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Challenges that novices face in applying core concepts to neuroscience contexts

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General Education (GE) courses field students from different majors with varied preconceptions of the life sciences, and neuroscience in particular. To aid instruction, outcomes, and assessment of students, core concepts are an effective tool that utilizes conceptual elements to promote learning and the transfer of knowledge between disciplines. This study examined students' prior understanding of two core concepts shared across biology and neuroscience—structure-function relationship and evolution—within the student population enrolled in GE neuroscience courses. The structure-function relationship core concept focuses on how characteristics of structures enable or constrain their function and vice versa, while the evolution core concept focuses on how similarities and differences in nervous systems between organisms are shaped by their shared ancestry and adaptations to their environments. Responses were analyzed using a deductive coding approach aimed to classify responses based on proficiency of conceptual understanding either within a general biology context or a neuroscience-specific context. Analysis revealed that the majority of non-biologists at the start of an introductory neuroscience course were unable to demonstrate comprehension of the structure-function (83.4%) or evolution core concept (67.0%) in either a general biology or neuroscience-specific context. Further inductive coding identified common themes that emerged from student responses, revealing student preconceptions of the Structure-function relationship and Evolution core concepts based on student major. These findings can aid educators by informing their selection of background information during course design and presentation of the material to positively shape students' understanding of these core concepts in GE classes.

KEYWORDS

core concepts, neuroscience, general education, evolution, structure-function relationship

Introduction

Students entering college must fulfill specific General Education (GE) requirements to graduate. These GE courses are meant to provide students with a well-rounded education through studies not strictly related to their major such as arts and humanities, social sciences, and natural sciences. Goals for GE courses differ from disciplinary, major-specific course goals that prepare students within their chosen discipline. GE courses aim to create intellectually-diverse adults, with a wide-range of basic understanding in multiple fields that are capable of making positive contributions to society (Newton, 2000). GE courses also fill the hard and soft skills-gap between pre-graduate students entering university and postgraduate students entering the workforce (Aloi et al., 2003). For example, a recent survey by the American Association of Colleges and Universities (AAC&U) found that employers value employees with both depth and breadth of knowledge, despite employers overall reporting that they consider postgraduates unprepared for the modern workforce (Finley, 2021).

Undergraduate students often fulfill their GE requirements in the life sciences by taking introductory neurosciences courses. The neuroscience field has grown immensely over the last two decades due to its interdisciplinary appeal, growth in novel technologies, and therapeutic applications (Akil et al., 2016; Schaefer, 2016; Ngai, 2022). The increasing number of undergraduate neuroscience programs globally (Pinard-Welyczko et al., 2017) provides opportunities for both major and non-major students to become exposed to the neuroscience field and content through major-specific and GE courses.

The design of GE courses compared to courses designed to be taken by majors may differ, as a result of their heterogeneous populations as well as their divergent aims. Broadly, an introductory neuroscience course designed for neuroscience majors seeks to provide a foundation for further coursework and studies in neuroscience. In contrast, GE courses are designed with the intention of students developing intellectual skills and gaining societal, civic, and global knowledge through a curriculum that exposes students to multiple modes of inquiry (Schejbal, 2017; Howard and Zoeller, 2007). Instructors may design GE neuroscience courses with less emphasis on preparing students to achieve immediate post-graduate goals but with a broader set of ideas that may be less immediately applicable but nevertheless useful. As a result, students entering neuroscience GE courses may face barriers that may not be experienced by students from within the major.

Unique challenges for GE students as compared to within-major students may arise because GE courses generally, and GE neuroscience courses specifically, consist of students from a wide variety of educational backgrounds. Before enrolling in these courses, students may vary in their prior knowledge, since enrolled students do not take a prescribed order of courses leading to a GE course. Educators may also face challenges in motivating students who do not appreciate the value of courses outside their discipline (Thompson et al., 2015; Humphreys and Davenport, 2005). Indeed, while students preparing for a neuroscience degree would have topics repeated in greater detail as they progress through the disciplinary coursework, students in GE classes would not receive this reiteration and will vary in their levels of prior knowledge and motivation. As a result, students in GE courses may show a wider range of knowledge exposure, knowledge retention, and academic performance.

In light of these objectives and challenges, it is imperative for neuroscience courses fulfilling GE requirements to focus on overarching principles for broader understanding rather than an emphasis on discipline-specific terminology. Core concepts promote cross-disciplinary learning by providing a framework of a subject's most fundamental principles. *Vision and Change in Undergraduate Biology Education: A Call to Action*, released in February 2010, emphasized the importance of core concepts in solidifying student understanding of the material and identified core concepts for biology (American Association for the Advancement of Science, 2011; Woodin et al., 2010; Ledbetter, 2012). Furthermore, the integration of core concepts reduces the overall amount of information students need to learn and retain, while also addressing any misconceptions that stem from incorrect prior knowledge (Danos et al., 2022).

Since the release of core concepts for general biology, other disciplines have developed core concepts of their own. Along these lines, a set of community-derived core concepts for neuroscience have recently been developed: (1) communication modalities; (2) emergence; (3) evolution; (4) gene-environment interactions; (5) information processing; (6) nervous system functions; (7) plasticity; (8) and structure-function relationship (Chen et al., 2023). These neuroscience core concepts are defined by multiple parameters including their ability to transcend across related subdisciplines, accurately convey conceptual elements in the simplest form, withstand new information, apply to all species comprising a nervous system, undergo deconstruction, and remain distinct from skills that can be taught (Chen et al., 2023).

Interestingly, two core concepts have striking similarities between the AAAS-organized national conference examining undergraduate biology education and the empirical study to identify neuroscience core concepts. Both neuroscience and biology have identified structure and function as a core concept for their fields. Biology educators emphasize that basic units of structure define the function of all living things, while neuroscience educators note that structure permits and constrains nervous system function and function shapes structure (American Association for the Advancement of Science, 2011; Chen et al., 2023). Both neuroscience and biology have also identified evolution as a core concept. In biology education, biology educators emphasize processes of mutation, selection, and genetic change that evolved the diversity of life; similarly, neuroscience educators noted that similarities and differences in nervous systems across species are constrained and defined by their evolutionary backgrounds (American Association for the Advancement of Science, 2011; Chen et al., 2023). Whether instructors choose to focus on biology core concepts or neuroscience core concepts when teaching neuroscience GE courses, it will be important to discern misunderstandings and knowledge gaps that are common when non-majors attempt to grasp structure-function relationships and/or evolution concepts.

In order to help instructors increase student comprehension and reduce potential misinterpretation of the material, this study aims to identify the various preconceptions that students outside the biological sciences have about the structure-function relationship and evolution core concepts. To do so, a deductive coding approach was used to investigate the proportion of student responses that incorporated biology conceptual elements and accurately applied the concept to the neuroscience context (Figure 1). The study also used a grounded theory approach to identify common themes when novices attempted to identify neuroscience examples of structure-function relationship and evolution. The aim of this study was to answer the following research questions:

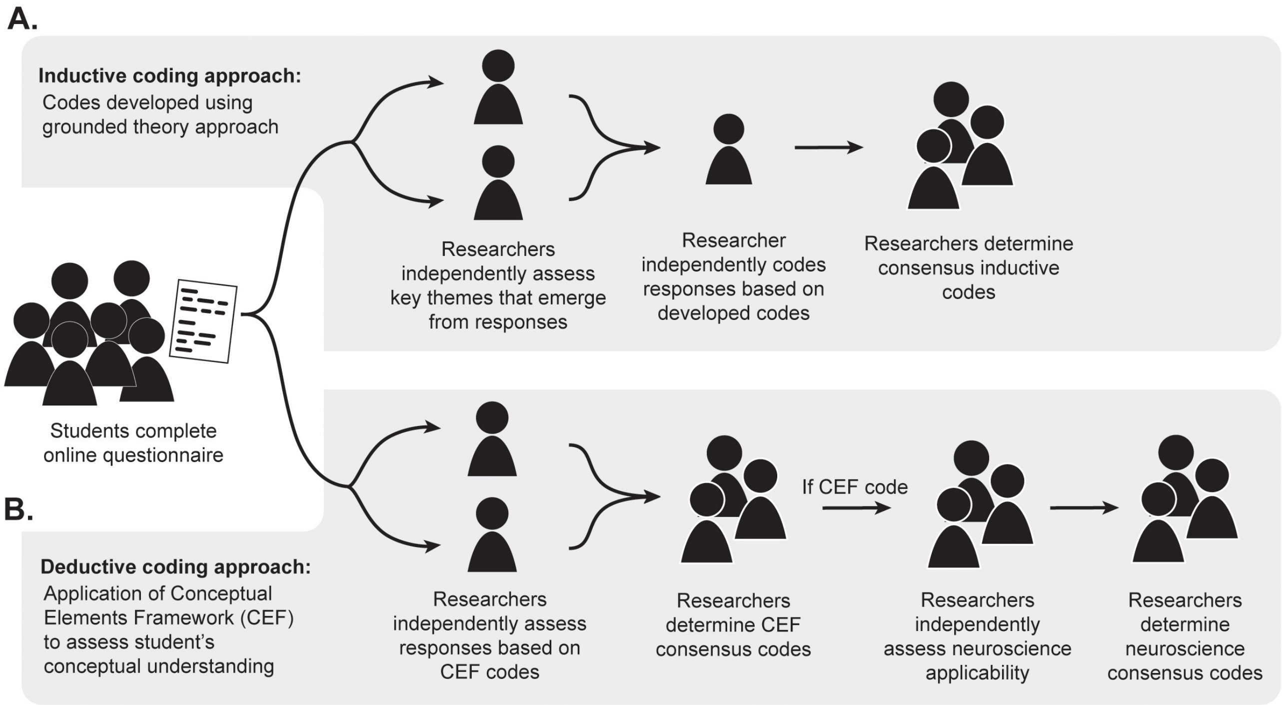

FIGURE 1
Overview of coding approach Student responses were analyzed using both an inductive and deductive coding approach. **(A)** In the inductive approach, researchers derived codes from the data (inductive codes). **(B)** In the deductive approach, researchers used the Conceptual Elements Framework to assess biology conceptual learning (deductive codes) and their application to a neuroscience context. In order to establish trustworthiness of data, researchers determined consensus codes following initial independent coding.

1. Do students enrolled in a general education neuroscience course have an understanding of structure-function relationship and evolution in biology but fail to accurately apply concepts in a neuroscience context?
2. What preconceptions do students outside the biological sciences have about the structure-function relationship core concept?
3. What preconceptions do students outside the biological sciences have about the evolution core concept?

Methods

Participants and study design

The studies involving human participants were considered exempt by the University of California, Irvine Institutional Review Board (IRB 2018-4211). Students were informed of the work with a study information sheet that specified an opt-out policy. Individuals who did not wish to participate in the research contacted a third-party through email and their data was not included in analysis. Prior to instruction, surveys were administered at an introductory neuroscience course at a large, research-intensive R1 public university in the western United States in Fall 2020. The introductory neuroscience course was a GE course which fulfilled a science and technology breadth requirement for graduation; students had a degree of choice in selecting a class that exposed them to the nature of scientific inquiry and the operation of the biological, physical, and technological world. A structure-function question was posed to students asking the following: "A core concept in biology is that structure informs function. To the best of your ability, please describe how structure informs function in neuroscience." An evolution question was posed to students asking the following: "Darwin's ideas about the diversity of life informed his theory of evolution. To the best of your ability, please describe a neuroscience example of this core concept." Survey questions were designed to introduce minimal bias while still defining some terms so that the survey question tested concepts apart from student familiarity with specific terminology. Students were instructed to answer with at least a 100-character minimum to obtain completion credit for the required assignment. Four hundred and ten participants attempted the survey, and responses were excluded if responses were only composed of non-sensical character strings or if institutional data reported different majors at different times. Following these exclusions, 342 participants were included in the study. To improve the comparability of the within-university majors to external universities, student majors were grouped by taking all participating majors and combining majors with commonalities together (see Supplementary Figure 1). Information about common departments, programs, and school groups informed research team discussions to determine commonalities. For example, the major "psychological sciences" was grouped with psychology. This yielded 14 major groupings.

Deductive coding approach

A deductive coding approach was used to determine whether student responses revealed evidence of elements of core concepts, and whether students were able to accurately connect the core concept to a neuroscience example (Figure 1). Using the Conceptual Elements Framework (Cary and Branchaw, 2017), two coders independently assessed if students showed evidence of understanding the core concept in a biology context. "And" statements present in the Conceptual Element Framework were adjusted to "or" statements to allow greater flexibility in what responses demonstrated understanding.

Understanding of structure-function relationship was demonstrated when student responses included one of the following ideas: SF1) Biological structures from the molecular to the ecosystem scale and their interactions are determined by chemical *or* physical properties that enable *or* constrain function; SF2) Individual structures can be arranged into organized units that enable more complex functions; SF3) Structural features of biological entities undergo changes during development that are determined by the regulation of gene expression; SF4) Structural features are dynamic and modifications can be made in response to environmental changes that are compensatory to restore lost function, or non-compensatory to eliminate functions that are no longer needed; SF5) Comparable changes in structure can have small or large effects on function, depending on the spatial function.

Understanding of evolution was demonstrated when student responses included one of the following ideas: E1) All living organisms share common ancestors at some time in the past; E2) The phenotypes of living organisms result from the gain and loss of traits along their lineage; E3) Genetic variation within a population can be generated by mutation, which results in the generation of novel traits, *or* by sexual recombination, endosymbiosis *or* horizontal gene transfer; E4) Phenotypes, based upon underlying genotypes *or* environmental factors, can be subject to selective pressure; E5) Organisms have greater fitness if they have a fitness that increases their ability to survive *or* reproduce in a particular environment; E6) Populations are composed of individual organisms that vary in their fitness, leading to differential rates of survival *or* reproduction and therefore changes in allele frequency over time; E7) Evolution in a population may be due to events not related to fitness, including genetic drift and gene flow; E8) The rate of evolutionary change varies and is influenced by many factors, including mutation rate, generation time, *or* environmental variation; E9) Speciation occurs when subpopulations can no longer exchange genetic material, allowing them to diverge over time in their physiological *or* ecological traits.

A simultaneous coding approach was used to capture if students presented evidence of understanding multiple aspects of biology core concepts. If a response did not reach a consensus on the deductive code, the response would be discussed with two additional researchers to determine a consensus.

Inductive coding approach

Student responses were examined using inductive coding following a grounded theory approach where thematic codes emerged in response to students' answers (Figure 1). Each question was initially coded by two independent coders to determine the themes present in the students' attempt to explain how the core concept applied to neuroscience. Codes were generated when new patterns were observed in the data. When continual data analysis found no new patterns, it was determined that code saturation had been achieved (Hennink et al., 2017). Once one coder was sufficiently trained, the remaining responses were coded by a single, independent coder.

Coding generated nine thematic codes for the structure-function question: (1) Legos; (2) Specific Area; (3) Chem Structure; (4) Lesion; (5) General Area; (6) Connectivity; (7) Characteristics; (8) No Answer; (9) Lack of Specificity (Table 1). For the evolution question, 13 unique thematic codes were generated: (1) Longitudinal; (2) Complexity; (3) Sociology; (4) Development; (5) Situational Adaptation; (6) Comparison; (7) Lack of Specificity; (8) Research; (9) Inheritance; (10) Survival Mechanism; (11) Variability; (12) Fitness; (13) No Answer (Table 2).

For each response, simultaneous coding (more than one code) was used when applicable. Responses with simultaneous coding applied were counted for each of their thematic code. This led to the total number of thematic codes outnumbering the original number of responses.

After inductive codes were generated for each response, a third independent coder reviewed each response to ensure they were accurately coded. Inductive codes were then compared to a blinded, single, independent coder to generate consensus inductive codes. If a response did not reach a consensus on the inductive codes, the responses were discussed with an additional researcher to determine a consensus.

Student ability to provide neuroscience examples of core concepts

Responses that demonstrated some proficiency in understanding the core concept regardless of context were further analyzed for their ability to accurately provide a neuroscience example of the core concept. Responses were considered to provide such an example if they were neuroscientifically accurate and mentioned a nervous system tissue or idea explicitly. Two separate coders independently evaluated whether a student response accurately connected the core concept to neuroscience. If a response did not reach a consensus on the deductive code, the response was discussed with two additional researchers to determine a consensus.

Data analysis

Data visualization and analyses were completed using Python 3.12.0 (Python Software Foundation), utilizing the numpy, pandas, matplotlib, plotly, and sklearn packages, alongside custom-written analysis scripts. Interrater reliability between coders utilized the Jaccard similarity index (Jaccard, 1901; Real and Vargas, 1996), given that student responses were allowed to be dual coded,

TABLE 1 Preconceptions of structure-function relationship.

Inductive code	Code definition	Example data
Characteristics	The response involves themes of highlighting the characteristics of shape, appearance, makeup, physical arrangements in space, or morphology of structures found in the nervous system, pertaining to structures which range anywhere from the cellular scale to a larger structural scale (for instance, the shape of the brain). The student response highlights at least one or several characteristics, in relation to particular structure(s) which have these characteristics, in order to implicate the functions of these structures or their general role.	*In neuroscience, structure informs function in the sense that how things are made help it produce certain actions. For instance, the spinal cord is a long tubular structure that consists of nervous tissue. Its shape allows it to extend from the brain (where it receives its information) out toward the whole body. Thus, the body is able to conduct movement and responses because of the spinal cord. Another example would be the Neuron and how its branched shape at one end allows it to receive signals efficiently.*
Chem structure	The response uses examples of chemical structures, such as those of molecules or neurotransmitters, to expand on how the composition of or structural morphology of these sub-cellular structures can influence function in the nervous system.	*Their are pathways, different shape of receptor cells, negative or positive electrons and lots of others things that shape their different function. For instance, their are hydroxy, carbonyl, carboxyl, amino...and many more function groups each have their own structure and bind with different R groups to function extremely different. A molecule or organic's structure decides whether it's hydrophobic or hydrophylic or more different properties.*
Connectivity	The response notes a physical connection or some type of communication between neurons, other brain structures, or different regions of the nervous system. The student comments on or expands on how these physical connections influence or inform overall function. A response that describes a functional connection would not fall under this category.	*In neuroscience, the possibility of neurons interacting with each other in different ways is due to the brain's structure. Different lobes are part of the brain's singular structure, all with unique characteristics and all communicating through neuroscience. Even at a molecular level of neurons themselves, there is a structure in each part of the neuron each area having a specific function in sending or receiving information throughout the brain.*
General area	The response uses an example of a non-specific region/area within the nervous system (e.g., "the brain," "neurons") and may either partially describe the structure's general task with little detail, fully describe the structure's general task with greater detail or intricacy in its related mechanisms, or may vaguely state that a structure has some neurobiologically-related function attached to it without delving into details. This code differs from the code "Structure X has a general function" because it does not focus into a specific nervous system region (e.g., Wernicke's Area would be considered a Structure X).	*In biology, the way the structure is arranged allows the organism to function correctly and successfully. In neuroscience, a nervous system is built to transmit signals among different parts of the body. Human bodies are structured to allow the brain to transmit signals to our body parts.*
Legos	The response may include examples which serve to highlight the different scales of the nervous system. This usually involves the juxtaposition of structures belonging to molecular scales and structures belonging to more macroscopic scales, leading to a brief description into their physical or functional connection(s) in relation to nervous system function. Responses also include those which highlight how smaller constituent parts of a structure work together to impact, influence, or constitute a larger nervous system structure. Themes in responses for "Legos" may also involve answers that do not have to explicitly state, but rather thematically surround the notion of "the sum is greater than the whole of its parts."	*In other words, every structure is a part of a whole. There are multiple structures that perform different tasks, but when putting multiple structures together they can form a single function. For example, the function of moving your hand requires structures from both your brain and structures from the muscle.*
Lesion	The response points out that the damage, removal, absence, or neurological dysfunction of a particular nervous system structure would impair or inhibit some neurological process that would have remained normal had the structure in question not become compromised. Behavior including drug use or unhealthy diets that lead to the damage or compromisation of structure also contribute the answer being coded "lesion."	*The way that something is made or arranged allows that structure to perform a certain function. Without certain elements in a structure, the structure won't be able to function as intended. The same is true if the structure is damaged in some physical way.*
Specific area	The response uses a specific nervous system structure, usually a specific structure found in the brain, and comments on their general normal-functioning role.	*My major is criminology law and society, and I learned knowledge about the amygdala. The amygdala has a close connection with aggression. The position and size of the amygdala can affect the different response of emotion.*
Lack of specificity	Vague response that is no incapsulated by other codes	*The best way I can describe how structure informs function is through the physiology of our hand. The structure of a human hand includes the bones for an opposable thumb. The structure of this thumb allows for fine motor movements and leads to the function of being able to hold items and do precise motor movements like writing. The structure of an organism lays out the foundation*
No answer	Student does not provide an answer for the question (blank cell) or does not attempt to answer the question.	*No answer*

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TABLE 2 Preconceptions of evolution.

Inductive code	Code definition	Example data
Comparison	Student response compares the capabilities or complexities of the nervous system among different non-human species, or between humans and non-human species. The comparison emphasizes either their similarities and/or differences in terms of nervous system complexity, or capability to perform certain functions as a result of that complexity. The responses may show, either implicitly or explicitly, how complexity serves to aid the characteristics of survivability or adaptability.	*Most animals have some sort of brain, however, not all of their brains are structured the same way. This is why animals can't speak fluent sentences or fly.*
Complexity	Student response points out that evolution over time produces a more complex, multi-layered, or functional diversification of the nervous system. Answers may thematically frame the nervous system as transitioning from a more basic framework to developing higher-level functioning with depth through evolution. The complexities which develop over evolution may involve the processes of learning, memory, or dynamic complex thought.	*In Darwin's perspective, he believed in the survival of the fittest and the theory of evolution which evolved for creation to become better, which would mean neuroscience, the way we process information and relay those information are much more advanced than they were before. Therefore, our neuroscience too is quite evolved.*
Development	Student response mentions the maturation or development of neurological abilities or neurologically-related structures. The maturation, growth, or increase in complexity of these abilities or structures is framed within the extent of a typical human life span. This is the defining feature of the code "Development." Though sometimes it is not explicated that this maturation/development occurs within a typical human life span, the examples are such that they allude to this shorter timeframe when the coder is thinking in the timeframe of millenia, or thousands of years. For example, typical answers may surround the development of a brain from a newborn/immature state to an adult state.	*The brain shrinking as you age. As we grow older, the brain's health declines and as a result our bodies' abilities worsens and memories begin to fade.*
Fitness	Student response mentions selective pressure on phenotype or a certain phenotype that increases a species' ability to survive and reproduce in a particular environment.	*In order for the Brian to pack in more neurons and develop more advanced cognitive abilities, the brain surface has developed many folds. According to Darwin's ideas, during the early stage of human history, those who has more folds in their brain showed stronger learning and adaptive abilities which increase their survival chance and the possibility to pass the traits to have more folds in the brain to their descendants*
Inheritance	Student response involve the concept of inheritation of genes, traits, or behaviors onto the next generation for a particular species, or species in general. This code differs from "Genes diversify function" because "Inheritance" coded responses focus more on the process of inheriting factors throughout evolution, and do not necessarily focus on the diversity of genes, traits, or behaviors and their relationship to function. Inherited items may include behaviors, physiolgoical systems, or genes. Although student responses tend to specify the particular systems or behaviors that are passed down, it is often the case that the genes (explained to be passed down and inherited) are not specified in terms of what they produce or encode more. More often, if genes are brought up, they are referred to as "genes" and not as "genes for X."	*Darwin's theory of evolution is mostly centered on natural selections. A neuroscience example of natural selection is the human species and other prime apes. The human species were more suited to their environments by using their brain to create tools, fire, and ways to farm. Other prime apes simply couldn't adapt to the harsh environment thus leading most prime ape species to end up dying off. The human species that survived pass on their superiors genes, which included high IQ among other things, to their offspring and the cycle repeats.*
Longitudinal	Student response highlights the fact that evolution happens over long times, e.g., over generations or over millenia. Student response may either briefly mention, or may largely emphasis the notion that evolution occurs over long periods of time. Language that students use may include, but is not limited to: "over hundreds of years," "generations," or "over millenia."	*Our brains are incredibly complex organs that evolved over thousands of years as we did alongside other species. Over time, our ancestors' brains helped them to become behaviorally distinct from their contemporaries until speciation occurred.*
Research	Student response involves the notion of education or teaching regarding evolution and how further discoveries down the line will help current scientists better understand the concept or mechanisms of evolution. The student may discuss archaeology or modern research in an attempt to propose how the extents of our neuroscience knowledge can be extended by advancements of understanding evolution. Student response may emphasize how researching the brain itself can aid our conceptual understand of evolution, using research tools and various scientific methods. An extended understanding of evolution emerges out of research, though the student may not specify to what end goal that knowledge might constitute.	*The diversity of people's personality is an example of neuroscience core concept. By studying different groups of people, neuroscience can advance just like the theory of evolution did. Neuroscience and people is like the theory of evolution and an evolutionary line of an animal.*

(Continued)

TABLE 2 (Continued)

Inductive code	Code definition	Example data
Situational adaptation	Student response touches on adaptation in the context of the short-term, or within an organism's life span. The examples of adaptation are not framed in the context of species adaptating to environments over the time span of evolution. For example, examples may mention change which occur in an organism as the organism relocates to a new environment (implicitly some time within their lifetime).	*Our bodies change to increase survivability in a given environment. One simple example is how we release adrenaline when we exercise. When we exercise, we are putting stress to our body and are making our body tired and hard to function through the pain. Adrenaline helps with these conditions and puts our body in a negative feedback loop which regulates the stress level using adrenaline.*
Sociology	Student response points out how cultures, societal expectations, behaviors, morals, or values may develop over time. These ideas may be connected to the idea of evolution, in terms of norms, values etc. being developed over long periods of time. The student may also connect these ideas in relation to their impact on brain function and/or brain processes.	*There are many differences between people because of different genetics and different stages of evolution. There are sometimes genetic disorders that are passed from parent to child and these can be explored by neuroscience. Neurologists look at these genetic disorders and try to see what caused them and how they can be prevented or treated effectively.*
Survival mechanism	Student response describes a survival mechanism. Many responses mention flight-or-fight, but also included some responses which describe threat response.	*We all have different personalities and creativity abilities due to our differences in the brain. Also, as time goes on, our brains continue to develop. For example, someone living on a ranch has a different brain than someone living in the city due to their different skills they have adapted for survival. Also someone who is blind has to focus more on their other senses as a mode of survival and to avoid danger. This is a way their brain has evolved from someone who is not blind and therefore does not need their other senses heightened.*
Variability	Student describes variability of a trait within one species. No mechanism is identified.	*Darwin's theory of evolution describes how many species all came from a common ancestor from which we evolved differently to suit our differing environmental needs. In order to survive, we developed certain brain functions that allowed us to better function in a harsh world. We developed the ability to use our senses, react to stimuli that appears to be dangerous and the ability to creatively solve problems. These functions allowed us to, over time, develop into a much more capable species that was able to not only survive, but thrive in the world.*
Lack of specificity	Vague response that is not incapsulated by other codes; for example, student response vaguely mentions that the brain has some ability, mechanism, or role.	*Darwin's theory of evolution is perfectly exemplified through the existence of the frontal lobe in humans. Because the frontal lobe is essential for functions such as understanding others and their actions, it allows us to empathize. This is something that is unique to humans' brains.*
No answer	Student does not provide an answer for the question (blank cell) or does not attempt to answer the question.	*No answer*

and standard similarity metrics, such as Cohen's Kappa (Cohen, 1960), are not suitable for dual coding approaches. The Jaccard similarity index quantifies the similarity between sample sets, in this case, each of the codes attributed to student responses. Codes were represented as a binary index along vectors of length equal to the total number of codes. For each student response, each code that the coders determined captured the response was assigned to a position on the vector (1 for the code being present in the response; 0 for the code not being present in the response). These vectors were then compared across coders by using the Jaccard similarity index. The interrater similarity between the inductive codes for Structure-function relationship (Jaccard similarity index = 0.84) and Evolution (Jaccard similarity index = 0.44) was determined. For the CEF codes, the similarity for Structure-function relationship (Jaccard similarity index = 0.75) and Evolution (Jaccard similarity index = 0.61) indicated high interrater similarity.

Since the codes determining student ability to apply their response to a neuroscience application were not dual-coded, Cohen's Kappa was used to determine reliability between the raters, where scores were determined for Structure-function relationship (Cohen's Kappa = 0.97) and Evolution (Cohen's Kappa = 0.98) responses.

Results

Students struggle to apply biological core concepts to neuroscience contexts

The study first aimed to determine whether student responses revealed evidence of utilizing elements of the core concepts understood as biological core concepts, and if so, whether the students were able to apply and connect the given concept to an accurate neuroscience example. Student responses were analyzed using a deductive coding approach, where each response was coded according to Cary and Branchaw's Conceptual Element Framework (CEF; see methods). Developed using an iterative approach involving more than 60 biologists and undergraduate biology educators, the CEF provides key components that transcend biology subdisciplines and scales for each overarching biological concept (Cary and Branchaw, 2017). The study sought to identify which conceptual elements were most prevalent in responses from students enrolled in introductory neuroscience general education courses targeted toward non-biologists at the start of instruction. Only a minority of student responses demonstrated any evidence of conceptual understanding of any element within the Structure-function relationship core concept (17%) or the Evolution core

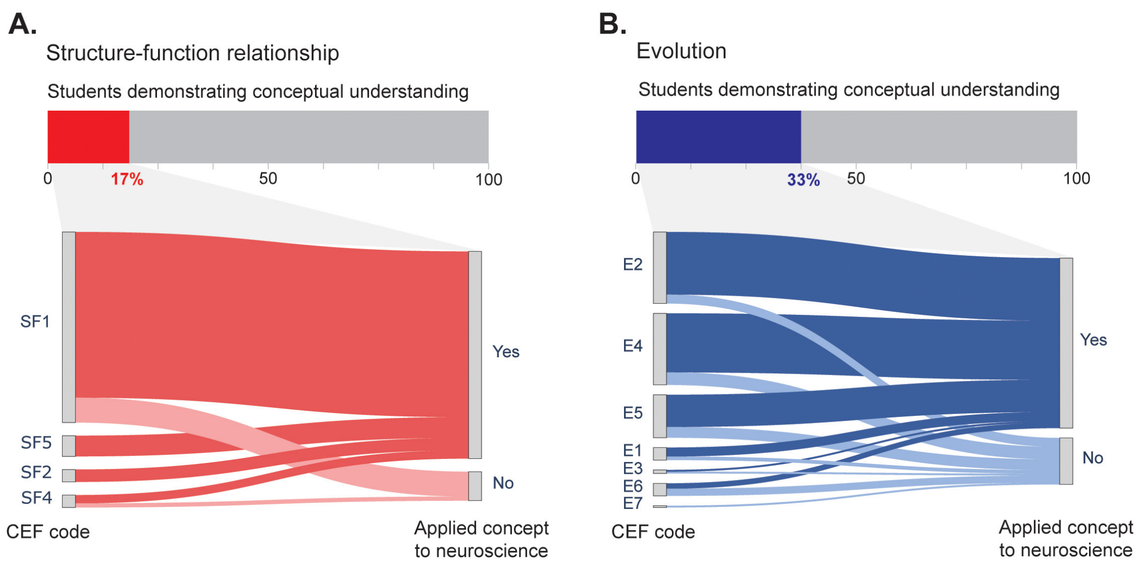

FIGURE 2
Student's understanding of biological core concepts and their relationship to neuroscience. Top: Proportion of student responses that demonstrated a conceptual understanding of the biological core-concepts as deductively coded according to the Conceptual Element Framework (CEF) developed by Cary and Branchaw (2017). Bottom: Of the students who demonstrated conceptual understanding, the proportion of CEF codes are shown on the left vertical axis. Connections between axes indicate the proportion of CEF codes that showcased a successful (yes; darker shade) or unsuccessful (no; lighter shade) connection back to neuroscience, depicted on the right vertical axis. Responses for prompting questions **(A)** Structure-function relationship (red) and **(B)** Evolution (blue) are shown.

concept (33%). Thus, the vast majority of the students struggled with accurately applying biological core concepts according to the CEF criteria in their responses (Figure 2 top).

When responses indicated some evidence of understanding the Structure-function relationship core concept, the majority of responses (80.7%) were captured by CEF code SF1 (Figure 2A), which highlights the idea that a biological structure's chemical or physical properties enable or constrain function. The second most prevalent conceptual element was SF5 (8.8%), with responses discussing how comparable changes in structure can have small or large effects on function, depending on spatial location. An equal percentage of students responded as SF2 and SF4 (5.3%). Responses coded as SF2 highlighted the arrangement of individual units can enable complex functions whereas responses coded as SF4 discussed the compensatory or non-compensatory structural modifications that arise from environmental changes. No responses were coded as SF3: structural changes during development are determined by gene regulation.

When responses were classified to contain evidence of an Evolution biological conceptual element from the CE Framework, the most prevalent conceptual elements were E2 (33.1%), focused on how an organism's phenotypes result from the gain or loss of traits along their lineage, and E4 (33.1%), which highlights how organisms can be subject to selective pressure (Figure 2B). 19.8% of student responses were coded for E5 and stated how an organism may have greater fitness if it has a quality that enables it to survive or reproduce in a particular environment. An equal percentage of students responded as E6 and E1 (5.8%). Responses coded as E6 discussed how varying fitness within a population eventually leads to changes in allele frequency over time while E1 focuses on the idea that all living organisms share common ancestors at some point in time. Only 1.7% of responses were coded as E3, which showcased that few student responses demonstrated what biological processes can generate novel traits. Only 0.8% of responses were coded for E7 which discussed the various mechanisms related to evolution, and were not natural selection, which may occur in a population. No responses were coded as E8: various factors that affect the rate of evolutionary change, or E9: process of speciation. Speciation, the process by which new species arise, occurs when groups of organisms within the same population become reproductively isolated and diverge to form a new species. However, many student responses suggested a belief that physical differences alone can lead to the formation of new species. For example, one student responded,

> "All life stemmed from a common ancestor and homologous structures of embryos is evidence of that. For example, all vertebrates started off with tails and gill slits as embryos but as they matured during the developmental stage, different species either kept or got rid of these features, thus leading to physical differences. And through evolution and natural selection, these physical differences led to the formation of new species."

The next step was to determine whether students with some demonstration of the core concept from a biological perspective were able to properly apply their understanding to a neuroscience setting. To answer this question, the proportion of students who provided a neuroscientifically accurate example was examined, among students who demonstrated evidence of a biology conceptual element in

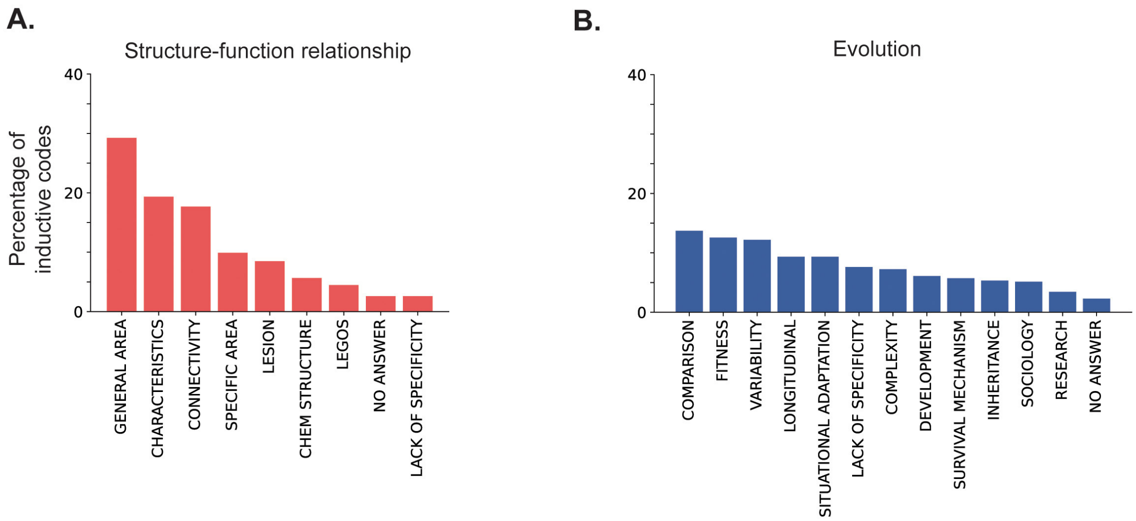

FIGURE 3
Frequent preconceptions of Structure-function relationship concept and Evolution concept. Proportion of inductive codes for Structure-function relationship **(A)** and Evolution **(B)** questions across all student responses. Code names are listed across the x-axis. Color indicates the core concept addressed.

their response. This revealed that the majority of students who were able to utilize the core concept in a biology sense were also able to accurately apply it to a neuroscience context, with 87.1% of the students for the Structure-function relationship prompt and 78.5% of the students for the Evolution prompt.

The majority of Structure-function relationship responses coded as SF1 (87.0%) or SF4 (66.7%) demonstrated a successful connection back to neuroscience. All responses coded as SF2 or SF5 showcased a successful connection back to neuroscience. A majority of Evolution responses coded as E2 (87.5%), E4 (82.5%), E5 (75.0%), or E1 (71.4%) demonstrated a successful connection back to neuroscience, whereas only half of the responses coded for E3 (50%) showed a successful connection. Conversely, some codes had a majority of students unable to connect back to neuroscience, such as E6, which had 57.1% of responses while E7 had 100% of responses unable to connect back to neuroscience.

What preconceptions do students outside the biological sciences have about the structure-function relationship core concept?

Since the majority of students entering a GE Neuroscience course do not understand elements of the structure-function relationship, the next step was to examine what ideas, and possible misconceptions they enter the class with. To fully capture the student responses without biasing the analysis, a grounded theory approach was used, where codes are derived from the student responses. Analysis of the prompting question of how structure informs function in neuroscience ("Structure-function relationship;" Figure 3A) revealed that the most prevalent code was "General Area" which captures student responses indicating a non-specific region in the nervous system and either partially or fully described its general function (29.0%). An example of this response was: "in neuroscience, a nervous system is built to transmit signals among different parts of the body; human bodies are structured to allow the brain to transmit signals to our body." A smaller portion of student responses (9.9%) reported a specific area has a function ("Specific Area;" Figure 3A). "Specific Area" differed from "General Area" because students mentioned a particular brain region and discussed its function, as opposed to general structures that may or may not relate to neurobiology. An example response: "the amygdala has a close connection with aggression; the position and size of the amygdala can affect the different response of emotion." Both of these responses suggest that students have not grasped the relationship between structure and function. While the structure-function relationship core concept is about structure permitting and constraining nervous system function and function shaping structure, students identify structure and function as two distinct entities. They believe that the core concept is about all structures having a function. For example, when one student was asked to provide a neuroscience example of structure informing function, they wrote,

> "The structure in the body is designed perfectly for it's own function, meaning everything has a purpose. This falls under neuroscience because since the structures have specific roles, it is the neurological point to make sure all the functions are working appropriately. Biology focuses on the structure and the function, the neuroscience is how the function is performed to it's best ability; so they work hand in hand with each other; I think."

In addition, this following example does not accurately distinguish the chemical and physical properties that enable or constrain a structure's function, further indicating that the student believes arrangement is equivalent to structure,

> "I believe that 'structure informs function' means in order for something operate it must have the correct composition. In terms of neuroscience, the concept can be exemplified through the presence of neurotransmitters. The structure of these molecules enables the transmission of messages between neurons. For the body to be informed and function properly when receiving these chemical messages, it requires the correct structure."

In order for students to understand the structure-function relationship, they need to identify characteristics of the structure that enable function (Kohn et al., 2018). Structure is thought of as the physical dimensions, three-dimensional shape, organization or arrangements of components that make a physical entity (Michael, 2021). 19.3% of responses were coded for "Characteristics," in which students commented on the appearance or morphology of structures in the nervous system to allude to its general role. 17.6% of responses were coded for "Connectivity." "Connectivity" encompasses responses that comment on how physical connections between neural structures influence or inform function.

What preconceptions do students outside the biological sciences have about the evolution core concept?

In order to aid instruction and facilitate student understanding of core concepts in neuroscience general education courses, the preconceptions enrolled students have about the evolution core concept prior to instruction were also examined (Figure 3B). "Comparison" responses were the most prevalent observed in the sample, with 13.7% of the codes. These responses differentiated the capabilities/complexities of neurobiological aspects between two species. A sample response mentioned that "most animals have some sort of brain, however, not all of their brains are structured the same way." 12.6% of responses were coded for "Fitness," in which students' responses mention selective pressure on phenotype or a certain phenotype can increase a species' ability to survive and reproduce in an environment. An example of this response is

> "According to Darwin's ideas, during the early stage of human history, those who has more folds in their brain showed stronger learning and adaptive abilities which increase their survival chance and the possibility to pass the traits to have more folds in the brain to their descendants."

12.1% of responses coded for "Variability," where responses described the variability of a trait within one species with no identifiable mechanism. Here, a student exemplifies this code through their response,

> "We developed the ability to use our senses, react to stimuli that appears to be dangerous and the ability to creatively solve problems. These functions allowed us to, over time, develop into a much more capable species that was able to not only survive, but thrive in the world."

Evolution is a population-level process that occurs over a long period of time; however, many students (9.3%) mistaken evolution for situational adaptation. For example, the following response shows a student had mistaken individual changes and adaptations for this continuous but gradual process,

> "Diversity is important as if there is no change, one can become stagnant and be unable to advance or move forward. In the brain, it is constantly evolving and making connections to learn and grow, because if it only stayed with the processes and functions it always makes, then it would not be able to handle new circumstances that cause different problems."

When attempting to provide neuroscience examples of the evolution core concept, students have a conception of evolution as maturing nervous systems or making them more complex. "Complexity" codes included student responses that discussed how evolution over time increased the complexity of the nervous system or highlighted the transition from a basic framework to a higher-functioning arrangement (7.2%). An example of this code has included student discussion on "the way we process information and relay those information are much more advanced than they were before; therefore, our neuroscience too is quite evolved." "Complexity" differed from "Development" as the latter code described responses that discussed the maturation of neurological abilities/structures within the species' lifespan. The code "Longitudinal" made up 9.3% of responses and emphasized evolution over a long period of time, along the lines of generations and millennia. This code differed from other codes due to an emphasis on a long time period, while other codes often emphasized other concepts outside of time.

Unfortunately, there was a substantial proportion (7.6%) of students who did not answer the question with enough specificity to identify any themes. "Lack of Specificity," encompassed responses that were not encapsulated by other codes and vaguely mentioned information attempting to answer the question. An example of this code was the response: "a neuroscience example of Darwin's theory of evolution in neuroscience would be the evolution of the brain conceptually and structurally."

Student's responses across majors are encompassed by heterogeneous codes

The variability in student's a priori understanding of core concepts was then examined in relation to their major at the time of the survey. To do so, while responses were coded blinded to student major, the proportion of students within a major whose responses were thematically similar was

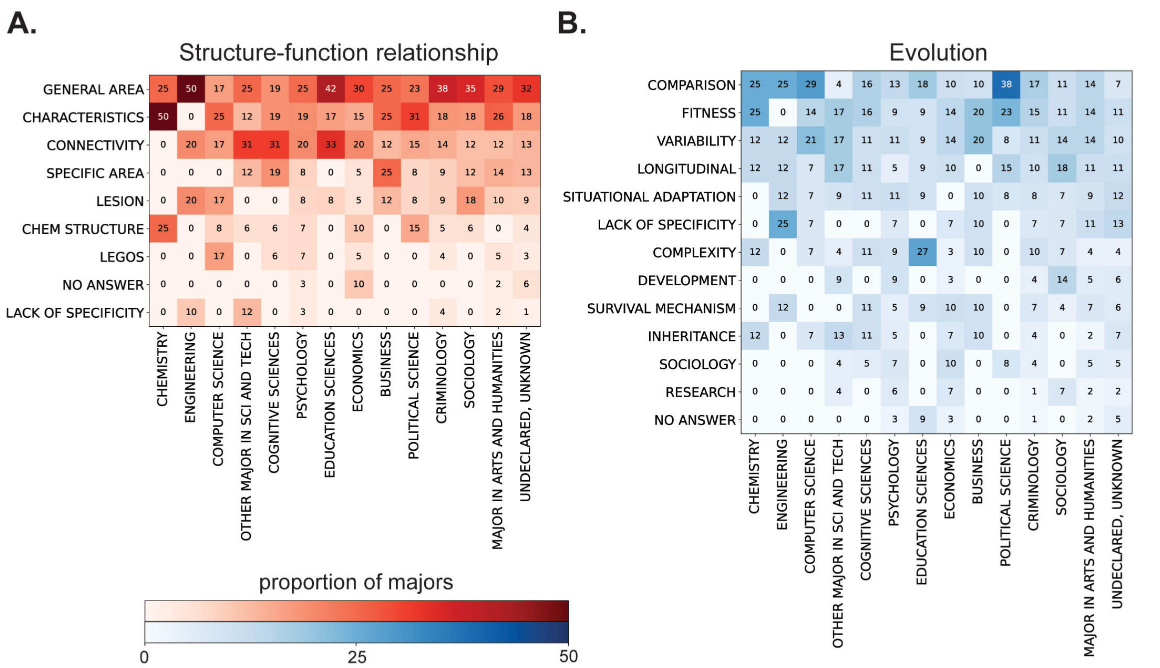

FIGURE 4
Frequent preconceptions of neuroscience core concepts organized by student major. Heat maps depict the proportion of students within a major (x-axis) whose responses were thematically similar for **(A)** Structure-function relationship and **(B)** Evolution core concepts (y-axis). Darker colors indicate a greater proportion of student's responses within a given thematic inductive code. Percent values rounded to nearest whole-number.

examined, and thus considered within the same inductive code (Figure 4). Across both questions, no single code dominated within a major.

The Structure-function relationship question demonstrated less variance in student's thematic responses across majors (Figure 4A). The three most frequent codes, "General Area," "Characteristics," and "Connectivity" showed robust prevalence across most of the majors. Students majoring in Engineering (50% of within-major codes), Education Sciences (42%), Criminology (38%), Sociology (33%), Undeclared, Unknown (32%), Economics (30%), and Major in Arts and Humanities (28%) preferentially responded with the most frequent code, "General Area." Alternatively, students majoring in Chemistry (50%), Political Science (31%), and Computer Science (25%) preferentially responded with "Characteristics." Students majoring in Cognitive science (31%) and Other Major in Science and Technology (31%) responded preferentially with "Connectivity." Sixty-six percentage of all responses across majors were thematically coded as these three most frequent codes.

Less prevalent codes displayed more heterogeneity within the various majors in the Structure-function question. Psychology majors, overrepresented in the sample, showed a slight preference for "General Area" followed by "Connectivity" and "Characteristics." All codes were represented by the psychology-major students, however the most prevalent major represented in the sample, showcasing heterogeneous response themes. Similar heterogeneity was also observed in undeclared major students, with all codes represented in the sample. Conversely, a few majors demonstrated far less variance across the codes. For example, Chemistry majors were restricted to three themes. While their responses predominantly exemplified "Characteristics" or "General area," 25% Chemistry majors' responses were coded with "Chem structure," the largest proportion compared to any other major.

The Evolution question showcased more variance in the most prevalent codes of student responses (Figure 3B). Owing to this, the top 5 most frequent codes comprised 57% of all student responses across all majors. "Comparison" was the most prevalent code across all students, with students in the Political Science (38%), Computer Science (29%), preferentially responding with the theme. Alternatively, responses from Education science majors were preferentially coded as "Complexity" (27%), more than any other major.

All codes were represented in the responses from Psychology majors, Criminology majors, Major in Arts and Humanities, and Undeclared, Unknown majors, with sparser sets across the other majors. Other majors including Chemistry, Engineering, Science and Technology, Cognitive Sciences, Economics, and Business saw no clear preference for any codes and showcased more heterogeneous responses. When examining the less prevalent secondary codes across the majors, it is observed that there is more heterogeneity within the various majors. Eight of the 14 majors (Chemistry, Engineering, Cognitive Sciences, Psychology, Economics, Business, Sociology) had tied secondary codes.

Discussion

Students generally, and non-major students specifically, may be aided by the use of core concepts, which promote cross-disciplinary learning through the utilization of a subject's most fundamental principles captured in a cohesive framework. Furthermore, educators can facilitate student understanding by designing key learning goals around core concepts and directly addressing students' previous understanding of core concepts (Kowalski and Taylor, 2009). Common student understandings of neuroscience core concepts, however, have not been explored. The present study assessed student understanding of two core concepts that overlap across biology and neuroscience: structure-function relationships and evolution. A deductive coding approach was developed to quantify the likelihood that non-major students understand biology conceptual elements of structure-function relationship and evolution with accurate applications to neuroscience. Additionally, an inductive coding approach was used to capture student preconceptions of these neuroscience core concepts prior to instruction.

It was found that while the majority of students began the introductory neuroscience GE course with the ability to present isolated facts, they lacked an understanding of the structure-function relationship and evolution concepts. The structure-function relationship concept addresses how structural properties enable functions at all levels of organization and the converse relationship that activity levels and functional demands of nervous systems can alter physical 3-D structures (Chen et al., 2023; Michael, 2021). Many students mistook the concept for the fact that the brain or specific structures have a particular task. Indeed, this could be a misconception further propagated by instructors who set learning objectives as recalling particular brain regions which regulate particular functions (Kötter, 2001; Cahyanto et al., 2019). To address a priori conceptions of the structure-function relationship, student-centered instruction can be accomplished through emphasis on how characteristic(s) enable or constrain function. Knowing this is a common misconception, educators and students should shift their perspectives from teaching and memorizing facts on which nervous system structure associates with which functions to developing a more thorough understanding of concepts (Wiggins and McTighe, 2005).

Similarly, many students have minimal understanding of the evolution concept prior to instruction. This core concept addresses how the similarities and differences in nervous systems between organisms are constrained and defined by their evolutionary backgrounds (Chen et al., 2023; Striedter, 2023). A number of responses indicate that students believe people evolved directly from monkeys. For example, one student eloquently but inaccurately noted,

> "A clear example will be the human evolution theory from the chimpanzees. There was a diversity of apes, monkeys, and chimpanzees millions of years ago that all started to breed between one another and genetically change with the centuries. After over 5 millions of years these diverse species of chimpanzees and other apes changed in physical and genetic form to look like us, humans."

Students often report thinking of evolution as a linear sequence of events, one where hominids, including apes, eventually turn into humans, a misconception likely popularized by influential artistic renditions of evolution which oversimplify the process (Green and Delgado, 2021; Tolman et al., 2021). These misunderstandings can form and be shaped outside of the classroom as well, with one study finding that 96% of the popular media that students report consuming inaccurately depicts evolution (Ferguson et al., 2022). Addressing misconceptions in education is key for boosting student understanding of fundamental concepts that make up the life sciences.

Using the Conceptual Elements Framework (CEF), only one-third of student responses exemplified any biology conceptual element of the evolution core concept and an even lower percentage for the structure-function relationship core concept. Students entering a neuroscience GE course have a dearth of knowledge surrounding core concepts. Strikingly, three conceptual elements were completely absent from student responses. Students did not reference the correlation of gene expression to structural changes during development (CEF element SF3), identify the many factors that vary the rate of evolutionary change (CEF element E8), or define speciation during the evolutionary process as the inability to exchange genetic information (CEF element E9). That is, the students may very well have the knowledge to address these points, but do not include these elements in their responses. Although experts may recognize that evolution encompasses several mechanisms beyond greater fitness, very few responses encompassed the conceptual element that evolution in a population may be due to events not related to fitness, including genetic drift and gene flow. The absence of these responses is an indication that students believe this phenomenon is limited to natural selection, and that ideas of genetic drift and gene flow are novel to students enrolled in a neuroscience GE course. Educators will need to decide whether these elements are best scaffolded later in the neuroscience curriculum for majors students, or whether some exposure to these elements are needed in an introductory neuroscience GE course.

Guiding students toward conceptual understanding rather than fact memorization will benefit them both within and beyond the neuroscience classroom. By condensing the list of required information through core concepts, students are better able to grasp the important ideas which helps foster retention and improve comprehension of the discipline (Brownell et al., 2014; Danos et al., 2022). Additionally, comprehension of transferable core concepts provides students with the scaffolding required to promote further learning and transfer to new contexts (Kaminske et al., 2020; Michael, 2022). Educators also benefit from a focus on core concepts as these overarching concepts provide educators with the luxury to draw upon their expertise and affinities to create a more enjoyable learning environment for students (Danos et al., 2022).

Implications for future course and curricula design

Teaching methods to address inaccurate preconceived notions could be developed to meet students where they stand. Further, as more instructors move toward teaching goals utilizing student learning of core concepts, as opposed to collections of facts, it is important for instructors to gain an understanding of the diversity of typical a priori understandings and misunderstandings of core concepts prior to course instruction. When instructors design class activities that connect neuroscience core concepts to students' preexisitng knowledge, students encode new knowledge relationally to prior knowledge, aiding memory formation in networks (Owens and Tanner, 2017).

Students majoring in the natural sciences, social sciences and humanities displayed different degrees of variation in their preconceptions of neuroscience core concepts, suggesting each major may benefit from tailored teaching approaches. As previously predicted, non-STEM majors possess a wide range of perspectives toward science (Cotner et al., 2017). When introducing neuroscience core concepts to students majoring in the arts and humanities, instructors can approach the material with the understanding that their students' perspectives are diverse and not shaped by a single viewpoint or idea. Some students in the arts and humanities may have some accurate understandings of the structure-function relationship concept that highlights characteristics of structures that implicate functional roles while others may have inaccurate understandings of the structure-function relationship which inappropriately associates general regions to tasks (Figure 4). However, it was rare to see students in the arts and humanities consider physical connections that influence or inform overall function, while this preconception was more common in students majoring in education sciences, cognitive sciences or other majors in science and technology (Figure 4). Therefore, when instructors design materials to teach structure-function relationship to students in the arts and humanities, they should not use connectivity examples to initially teach how structure informs function but may want to apply the core concept to physical connections only after students have first learned the core concept related to other physical attributes.

In the future, the neuroscience educator community can develop resources to aid fellow educators in identifying misconceptions and teaching neuroscience core concepts, similar to the resources that have been developed for biology core concepts. While the inclusion of core concepts in neuroscience pedagogy is relatively new and evidence-based interventions testing methods to include core concepts are limited, several institutions are beginning to embed neuroscience core concepts in curricular planning (Maita et al., 2024; Proksch et al., 2024; Stocker and Duncan, 2024) and the neuroscience education community is brainstorming concrete methods to utilize core concepts in teaching (Chen et al., 2024). Gleaning from the history of how biology core concepts were adopted into biology curricula (Branchaw et al., 2020; Brownell et al., 2014), the neuroscience educator community will need to collectively and iteratively identify conceptual elements that can be easily applied across neuroscience scales and subdisciplines. This work is currently underway. With this unpacking, instruments that assess student learning and instructional reform will have greater clarity in a structured framework. The unpacking will also be useful as publishers begin to explicitly incorporate neuroscience core concepts into textbooks similar to the Integrating Concepts in Biology textbook which interleaves biology core concepts (Campbell et al., 2024). Learning objectives can be tailored to the knowledge gaps presented by student answers, focusing more explicitly on core concepts. In the future, the neuroscience education community can decide whether a nationally endorsed set of lesson-level learning objectives can be developed for neuroscience coursework for neuroscience majors as they have been for general biology (Orr et al., 2022; Hennessey and Freeman, 2024).

It may also be beneficial to develop a NeuroCore Guide that provides specific interpretations of neuroscience core concepts for different subdisciplines in neuroscience which spans multiple levels of scale, ranging from molecular/cellular neurobiology to social neuroscience. This resource would mirror the BioCore Guide developed for biology (Brownell et al., 2014). Currently there are no validated assessments of neuroscience core concepts, but the neuroscience education community is currently in the process of developing concept inventories, similar to GenBio-MAPS that were developed for programmatic assessment of general biology programs (Couch et al., 2019), Eco-Evo-MAPS for ecology and evolution assessment (Summers et al., 2018), and Phys-MAPS for physiology (Semsar et al., 2019). Lessons can also be learned from the recent NSF-funded project that aims to develop and publish a collection of biology core concept teaching tools to help students transfer and apply their knowledge across scales and sub-disciplines. While the currently funded project develops tools to teach biology core concepts, the program can be used as a prototype of methods to recruit and lead educators with expertise from multiple neuroscience sub-disciplines and institution types on how to develop a collection of neuroscience core concept teaching tools.

As teaching tools are developed, the educator community should be cognizant of the diversity of teaching contexts. Laboratory courses, which use more hands-on teaching activities, will need resources to allow students to see core concepts recurrent also in laboratory experiments. Infrastructural differences, such as whether a neuroscience course is housed in Psychology, Cognitive Science or Biology, may also affect an instructor's decision on which core concepts to emphasize within their course (Maita et al., 2024). Institutional type may also affect the administrative ease in fomenting change.

Further, developing learning goals for students may differ between major and non-major students, such as those enrolled in GE courses. Non-major students taking neuroscience GE courses face unique challenges compared to within-major students. These challenges stem from the fact that students enrolled in GE courses often have diverse subject matter backgrounds, biases, motives for enrolling in a course, and levels of motivation (Glynn et al., 2005; Thompson et al., 2015). Non-major students may not be as fully immersed in biology education, or even STEM education generally, ultimately facing fewer opportunities to be exposed to these underlying concepts prior to entering a GE course. While students in the major benefit from repeated emphasis of the fundamental concepts across an array of biology courses, which collectively provide a comprehensive understanding by the time students finish their curricula, non-major students enrolled in a neuroscience GE course may only have exposure in one class. Educators face the dilemma of choosing between exposing students to key concepts that may be useful across a number of real-life applications, or piquing student interest with an in-depth look at one interesting phenomenon. The limited time students may be exposed to these courses may limit the extent to which these concepts can be adequately addressed. Narratives which describe a compelling complex neuroscience phenomenon with embedded illustrations of core concepts may be an effective core concept teaching tool to strike a balance between these competing interests. Consequently, the design of GE neuroscience courses compared to within-major courses may differ, and can be informed by further understanding the student population enrolling in these courses. Students fielded from heterogeneous backgrounds carry an array of misconceptions with them as they enter courses. When preconceptions are appropriately quantified, instructors may be able to use this information to their advantage. Although it may not be possible to completely eliminate neuromyths and misconceptions of core concepts, increased exposure to accurate pedagogical knowledge can reduce the propagation of misconceptions (Macdonald et al., 2017).

From an educator's perspective, knowledge of common preconceptions of core concepts may provide a tool for educators to meet students where they stand prior to course enrollment. If conceptual understanding is known, or at least estimated prior to course design, or even instruction, the course can be tailored to dispel the most common misconceptions based on the population's students. Regardless of this information, however, general knowledge of the various misconceptions that their students are likely to enter the classroom which can help instructors shape their teaching methods to the students (Kowalski and Taylor, 2009). The onus is on instructors to address and correct any misconceptions students may have about the course's core concepts based upon the needs of their specific student population.

Limitations

Limitations of these data include the student population. Psychology students were the majority of majors in the sample compared with other majors. It is not surprising that Psychology students are overrepresented in the sample, since their discipline complements and overlaps with neuroscience material, and they are more likely to enroll in a Neuroscience course for life science GE credit. Conversely, other majors included a more limited number of students (see Supplementary Figure 1B). Ongoing work is to sample from students outside of Psychology in order to find trends in less represented majors who enroll in Neuroscience GE classes. Future work with a larger sample size will allow analysis of distinctions between students majoring in the natural sciences, social sciences vs. humanities. Thus, replication with a broader sample, including to other types of degree granting universities and programs, is needed to extend the applicability of the results and to fully explore the heterogeneity of the student population.

Given the scales, complexity, and broad interdisciplinary nature of neuroscience courses, teaching of core concepts allows consistency even when the particular neuroscience subject matter chosen by the department or instructor for each specific course varies. However, our study does not attempt to describe student preconceptions of core concepts from students majoring in Neuroscience as they proceed through the Neuroscience curriculum. Indeed a study of neuroscience majors from 118 colleges and universities in the United States revealed striking variability across neuroscience courses (Pinard-Welyczko et al., 2017), making the task of characterizing student perceptions along the Neurobiology curriculum challenging.

While the survey was designed to introduce minimal bias while still defining some terms so that the survey question tested concepts apart from student familiarity with specific terminology, future surveys can assess student conceptions of neuroscience core concepts by targeting application of the core concept to specific neuroscience phenomenon. This approach may reveal misconceptions that the current study was unable to uncover.

Conclusion

A cornerstone of the liberal arts tradition, GE courses trace their lineage across thousands of years to the ancient Greeks and Romans (Bourke et al., 2009). Neuroscience courses have the potential to be great general life science courses for students. The broad, interdisciplinary nature of neuroscience courses relates the life sciences directly to students themselves on a subject that has garnered growing public interest and applications. At the same time, this wide-ranging and potentially complex subject matter may be difficult for many students to fully grasp. The implications of this study allow instructors to address the needs and preconceptions of students from heterogeneous backgrounds. It is imperative for future work to further address student's conceptual understanding of core concepts that can be further utilized to improve course design and student achievement.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of California, Irvine Office of Research Human Research Protections. The studies were conducted in accordance with the local legislation and institutional requirements. The Ethics Committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because research, conducted in established or commonly accepted educational settings and specifically involves normal educational practice that are not likely to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction. Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation. No behavioral interventions were involved. Study information sheets were provided with contact information to opt out of the research study.

Author contributions

KC: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Data curation, Validation, Visualization. ET: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing –

original draft, Writing – review & editing. BM: Formal analysis, Investigation, Writing – original draft, Writing – review & editing. TL: Formal analysis, Investigation, Writing – original draft. CT: Formal analysis, Writing – original draft, Writing – review & editing. DG: Formal analysis, Writing – original draft, Writing – review & editing. AD: Investigation, Writing – original draft, Writing – review & editing. AC: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Supervision, 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.2025.1488892/full#supplementary-material

SUPPLEMENTARY FIGURE S1
Groupings of majors and percentage of each major in the present sample. **(A)** To improve the comparability of the intra-university majors to external universities, student majors were grouped into 14 categories encompassing each of the primary disciplines. Majors which appeared scarcely in the sample were also grouped. **(B)** Proportions of each major grouping that appeared in the student sample.

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