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Jeremy L. Hsu

Patricia A. Halpin

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Exploring physiology instructors' use of core concepts: Pedagogical factors that influence choice of course topics

Jeremy L. Hsu[1*] and Patricia A. Halpin[2]

[1] Schmid College of Science and Technology, Chapman University, Orange, CA 92866

[2] Department of Life Sciences, University of New Hampshire, Manchester, NH 03101

* corresponding author: Jeremy L. Hsu, hsu@chapman.edu, One University Dr, Orange, CA 92866

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Abstract

The physiology core concepts are designed to guide instructors in undergraduate physiology courses. However, while past work has characterized the alignment of physiology programs with the core concepts, it is unclear to what extent these core concepts have influenced instructors' pedagogical decisions, or how represented these core concepts are across physiology courses. We surveyed undergraduate physiology instructors to determine their familiarity with the core concepts, the impact of the core concepts on their teaching, as well as the alignment of their courses to these core concepts. Instructors report predominantly relying on textbooks and past syllabi of their courses as resources that influence their instructional decisions on which topics to include in a course. However, many instructors report re-organizing their physiology courses in subsequent iterations or reducing the number of concepts covered to allow more time for critical thinking and active learning. In addition, we find that the majority of instructors indicate that they are not knowledgeable about the list of physiology core concepts, and that the influence of these core concepts is limited even for those who report familiarity with the list of core concepts. Finally, we find that instructors report uneven coverage of physiology core concepts in their courses, with some core concepts ubiquitous while others are sparsely covered. We conclude by discussing implications of our work for the physiology education community and call for the continued development of resources to support new physiology instructors and the need to promote coverage of certain core concepts in physiology courses.

Introduction

Instructors teaching a course face a range of pedagogical decisions, including choices regarding how to structure their courses, what activities to include, and what topics to cover (1, 2). These decisions are particularly important the first time an instructor teaches a course, given that instructors' personal experiences in the classroom will likely play a significant role in shaping their future pedagogical decisions (3). Despite the importance of instructors' pedagogical decisions, it remains unclear what drives such choices. Similarly, it is unclear what resources instructors rely on when designing a course, either the first time they teach a course or in subsequent iterations of the course.

One resource that has been developed for instructors in various science, technology, engineering, and math (STEM) disciplines are core concepts for that discipline (4–8). Core concepts represent a list of fundamental ideas that are central to a discipline, and can represent a set of knowledge that is deemed critical for undergraduates studying that discipline (9). Such core concepts are typically developed through an iterative process that involves input from faculty, researchers, and educators in that field (4). Once developed, core concepts can enable the development of pedagogical frameworks, curricular modules, and assessments aligned with the core concepts and facilitate introspective looks into how well undergraduate programs are aligned with and teaching the core concepts (10–12).

However, despite the increase in the number of published core concepts in STEM, the extent to which such core concepts influence instructional decisions remains unknown. Here, we investigate the influence of core concepts and instructors' pedagogical choices regarding choice of topics in the context of undergraduate physiology courses. There are several advantages for examining core concepts in physiology education. First, the discipline has a set of core concepts that have been endorsed by the American Physiological Society (APS), the largest general physiology organization in the United States (5, 13, 14). These core concepts were first developed over a decade ago, allowing sufficient time for the core concepts to be disseminated and implemented throughout the physiology education curriculum. Second, there have been multiple studies involving these core concepts, allowing us to situate our work in the broader ecosystem of studies examining the physiology core concepts. This past work includes updates and refinements to the list of core concepts (13, 15), examinations of the alignment of specific undergraduate physiology degree programs with core concepts (16), surveys and reflections of students and faculty in physiology degree programs on the relative coverage of each core concept (12, 16, 17), and development of curriculum and assessment aligned with the core concepts (18, 19). Despite this, there remains a gap in knowledge of how familiar physiology instructors across institutions are with the core concepts, since past surveys have only included instructors in undergraduate physiology degree programs (16). Similarly, it remains unclear how much this resource is utilized when instructors are teaching a course for the first time or in subsequent iterations.

We also note that there is an increasing need to examine instructor decisions regarding choice of topics in physiology. For instance, there have been calls to reduce the amount of content in physiology courses to instead focus on deep, conceptual learning of the remaining concepts across the physiology curriculum (19–21). To support such pedagogical transformations, it is critical that we investigate the resources that undergraduate physiology instructors rely on when making these pedagogical decisionsand explore the extent that the physiology core concepts are being used by the undergraduate physiology education community.

Thus, our work addresses the following research questions:

1) What resources do instructors draw from when designing and teaching a physiology course the first time?
2) What do instructors report as the main factors that cause them to add or remove topics to their physiology courses?
3) How familiar are physiology instructors with the physiology core concepts, and to what extent do the core concepts influence pedagogical decisions?
4) Which core concepts are most and least frequently taught in undergraduate physiology courses?

Methods

A mixed methods survey with both qualitative (free response) and quantitative questions was designed to capture respondents' familiarity with the physiology core concepts, as well as what resources they rely on when designing and teaching their physiology courses. The survey was sent through the email listserv for the American Physiological Society (APS) Teaching of Physiology Section, as well as through those of the Society for the Advancement of Biology Education Research (SABER) and the Promoting Active Learning and Mentoring (PALM) Network. Participation in the survey was incentivized with a drawing for gift cards. Responses were only collected if respondents indicated that they had taught at least one undergraduate physiology course within the last five years. One hundred and forty-six responses were collected; after filtering for incomplete responses and those that indicated that they had not taught a physiology course recently, 135 responses (92.5%) remained in our dataset. Of those, over 70% (95 respondents) responded to each question that they were asked on the survey. However, we included responses from each participant for every question to maximize the breadth of physiology instructors' perspectives. Quantitative responses were compared between different demographic groups using R. Qualitative responses were analyzed using inductive grounded theory, with both participants first independently reading responses to identify key themes before generating a consensus codebook (22). Given the relatively low number of responses to code, the two authors independently read each response and discussed before coming to a consensus. The protocol was approved by the Chapman University Institutional Review Board as exempt.

Results

Respondent demographics

Responses came from instructors at a diversity of institutions, representing instructors with a range of different experiences. First, instructors were provided an optional box to indicate the name of their current institution; 95 instructors opted to include this information. These 95 instructors represented 91 different institutions. The plurality (36.4%) of respondents indicated that they were instructors at research-intensive (R1) universities, with 24% indicating that they were at a R2 or comprehensive university. Fifteen percent (15.7%) of respondents were from small, liberal arts colleges, with 9% from two-year colleges. The plurality of respondents (32.1%) indicated that they were full professor, followed by 27.8% as associate professor, 21.4% assistant professors, and the remaining 18.8% as lecturers, part-time faculty, and other instructor positions. Similarly, the vast majority (84%) of respondents indicated that they had been teaching for more than 5 years, with only 16% indicating that they had taught for fewer than five years. We chose 5 years as a metric to distinguish between those who were relatively new to teaching undergraduate physiology courses from those with more experience in teaching these courses. Nearly two thirds of the instructors (64.6%) indicated that they taught mid- or upper-level physiology courses most regularly, with 28.2% teaching introductory physiology. The remaining 7.3% indicated that they taught courses for non-majors that incorporated physiology.

What resources do instructors draw from when designing and teaching a physiology course the first time?

The survey asked respondents to consider the physiology course they taught most recently and reflect upon their experiences when designing the course and selecting the topics for the course. A list of possible resources was included for respondents to choose. Textbooks were the most common resource referred to (80%), followed by past syllabi (64%), colleagues within the respondent's own institution (56%), colleagues outside the institution (36%), and syllabi from other physiology courses (32%). Over a third (36%) of respondents indicated that they had consulted APS educational resources, while over a quarter (27%) indicated that they had referred to the physiology core concepts from Michael and McFarland (2011).Less than a fourth (22%) of respondents indicated that they had looked at *Vision & Change* core concepts. There were no differences in the frequency of each resource used when responses were compared by level of physiology course taught, number of years of teaching, or type of institution (Chi-squared test, alpha = 0.05).

What do instructors report as the main factors that cause them to add or remove topics to their physiology courses?

Instructors were asked if they had taught their physiology course more than once and if the list of topics had changed. Approximately three-quarters of instructors (74.3%) reported teaching their course multiple times and changing the topics in the course. Instructors reported a variety of reasons for why they varied their topics when teaching the course again (table 1), with the most common response (23.5% of codes) being a re-organization of the course topics to better address course themes. The second most common response (16.3% of codes) was that instructors had cut down on content to have more time to dedicate to active learning strategies and/or critical thinking, including focusing on specific skills and competencies. The third most common response (12.2%) reflected addition of new material due to developments in the field of physiology. Interestingly, some instructors (11.2% of codes) indicated that they had updated their course content in response to learning objectives and core concepts. Instructors cited both the Michael and McFarland (2011) physiology core concepts as well as other published learning outcomes, including those from the Human Anatomy and Physiology Society (HAPS) (23). A range of other reasons was also cited, including decreasing course content due to curricular reorganization or time pressures (9.2% for both), changing the list of topics due to student performance in past courses (8.2%), programmatic needs (7.1%), or to better prepare students for specific careers (3.1%). There were no differences based on type of course taught. Given that over a fourth of instructors indicated that they had not taught the same physiology course again, , the sample size of responses (n=90) was too small to meaningfully compare responses by number of years teaching or institution type.

Table 1. List of emergent codes for when instructors what led them to add or remove concepts from their physiology courses.

Code name	**Code description**	**Example quotes**	**Percent of codes**

Organization	Shifted how content was presented in terms of thematic approaches, or changed the focus for different topics	“For about the past 15 years I've shifted from a march through organ system function (as most textbooks are organized) to more of a "Topics in..." approach. For example, we focus on histamine as a versatile chemical message, pain as an example of complex sensory processing, and the regulation of MAP in exercise and volume depletion.”	23.5%
Less is more	Discussed how they trimmed down content to focus more on critical thinking, active learning, present current information better, focus on skills (rather than content), or allow for other in class activities.	“We have to remove concepts to make way for time spent on active learning, study skills, and anything else that the next generation of student population needs. I strategically removed advanced things like counter current exchange as it's noted in the HAPS outcomes why that can be omitted. I also removed things that don't map back to a core idea like gradients and flow, feedback loops. If it's simply a seemingly random fact and can't be applied later, it's at risk for being removed from the curricula.”	16.3%
New concepts	Added new topics as science progressed	“To add concepts is more frequent if there are emerging areas of knowledge”	12.2%
Learning outcomes and assessments	Changes, if any, were driven by learning objectives, core concepts, or published assessments	“I rely heavily on the [Human Anatomy and Physiology Society] learning outcomes”	11.2%
Other course	Cited being able to move some concepts to a concurrent lab course or that topics would be covered by another course, allowing for fewer topics in lecture	“There were some less important concepts that could be moved to be covered in lab, allowing for more time to focus on more important concepts in lecture.”	9.2%
Time	Decreased content due to time pressures	“I have removed some concepts because the course	9.2%

		was too tight on time. I choose to remove concepts that I thought were not classically taught in exercise physiology courses.”	
Student performance	Changes were made to course content based on student performance	“Addition of concepts was usually due to a lack of understanding. I had assumed that the concept was inherent and assumed students would pick up on the concept on their own. When that wasn't the case, I added the concept. Removal of concepts was due to the fact that the concept proved too difficult for the students to master. Usually, this meant that I backed off on the depth at which I taught the concept.”	8.2%
Programmatic	Changes were made in response to programmatic needs or demands, including changes to course unit/credit load, or from discussions from administrators (i.e., changes were likely not instructor driven)	“Feedback from the PA program and seeing their syllabus, my own ability to conceptually link topics together in a structured fashion that lent itself more to the students being able to link systems together and critically think about physiological process.”	7.1%
Careers	Changes were made in response to better prepare students for specific careers	“The course has become less comparative and focused more on human physiology- due to the students enrolled in the course. They are primarily oriented towards careers in various health professions.”	3.1%

How familiar are physiology instructors with the physiology core concepts, and to what extent do the core concepts influence pedagogical decisions?

Most respondents (62.4%) indicated that they were either not familiar with (39.6%) or only minimally familiar with (22.8%) the physiology core concepts from Michael and McFarland (2011). Approximately an eighth of respondents (12.9%) indicated moderate familiarity, with 14.8% reporting that they were very familiar and 9.9% extremely familiar with these core concepts. Similarly, a minority of respondents (27%) indicated that they used the core concepts when choosing the list of topics for their physiology courses. Approximately 11% of respondents cited these core concepts, or other learning objectives from professional societies, as a factor in adding or removing topics from their courses when a course was repeated. There were no differences in respondents' reported familiarity with the physiology core concepts based on level of physiology course taught, institution type, or number of years teaching physiology.

Which core concepts are most and least frequently taught in undergraduate physiology courses?

Instructors were asked to evaluate the coverage of each of the physiology core concepts in their physiology courses. We implemented the same scale used in a previous curricular survey examining the frequency of physiology core concepts across undergraduate physiology programs (16), with instructors asked to identify if each core concept was not covered, minimally covered, or covered in significant detail. These responses were then scored as a value of 1 (not covered), 2, (minimally covered), or 3 (covered in significant detail). Different core concepts were covered in different degrees of depths across courses (Figure 1). There were no differences in the level of coverage of each core concept based on level of physiology course taught, institution type, or number of years teaching physiology (Chi-squared test with post hoc Bonferroni correction, alpha = 0.05).

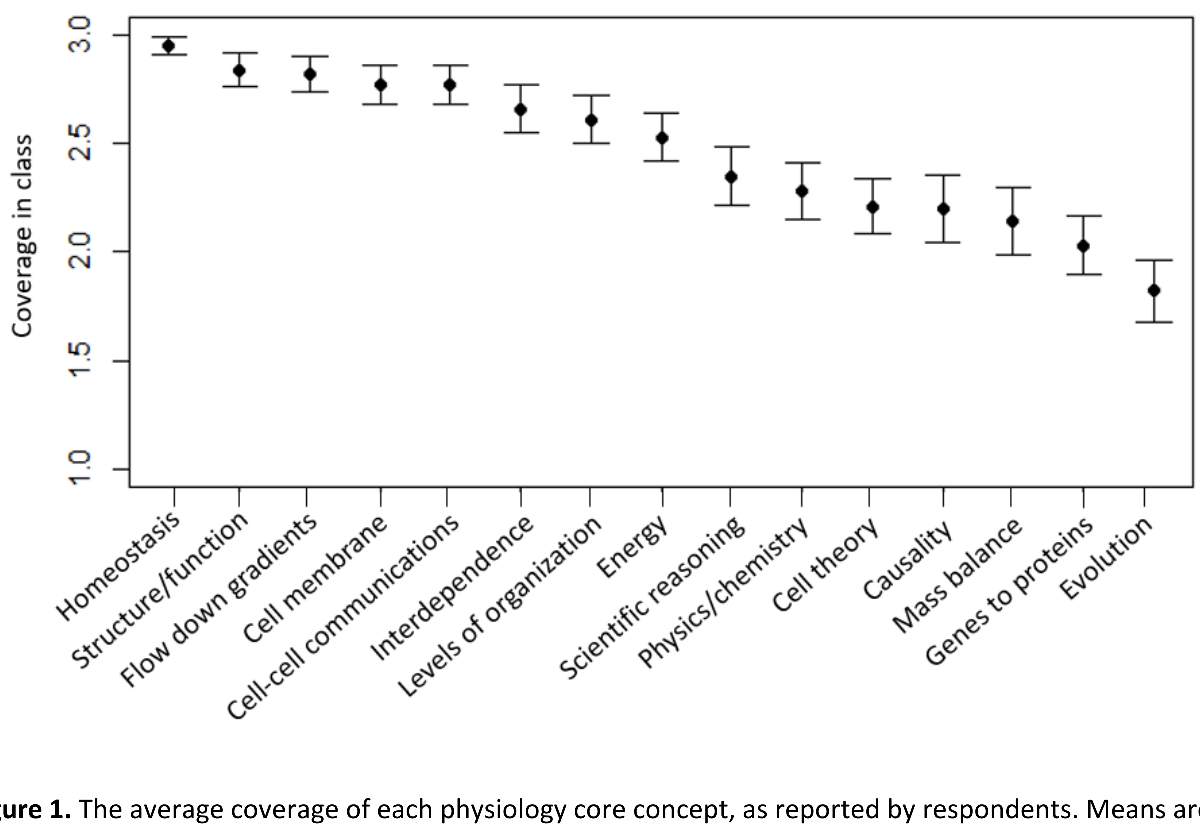

Figure 1. The average coverage of each physiology core concept, as reported by respondents. Means are provided based on a three point scale, as used in (16), where 1 represents a core concept that is not

covered in the course, 2 represents minimal coverage, and 3 represents coverage in significant detail. Error bars represent 95% confidence intervals

Table 2. List of physiology core concepts (13) and percent of respondents indicating that the core concept is not covered in their most recent physiology course, minimally covered, or covered in significant detail

Core concept	Core concept covered in significant detail	Core concept minimally covered in course	Core concept not covered in course
Homeostasis: The internal environment of the organism is actively maintained constant by the function of cells, tissues, and organs organized in a negative feedback system	94.8%	5.2%	0%
Structure/function: The function of a cell, tissue, or organ is determined by its form. Structure and function (from the molecular level to the organ system level) are intrinsically related to each other.	84.5%	14.4%	1.0%
Flow down gradients: The transport of "stuff" (ions, molecules, blood, and air) is a central process at all levels of organization in the organism, and this transport is described by a simple model.	83.3%	15.6%	1%
Cell membrane: Plasma membranes are complex structures that determine what substances enter or leave the cell. They are essential for cell signaling, transport, and other processes.	77.9%	21.1%	1%
Cell-cell communications: The function of the organism requires that cells pass information to one another to coordinate their activities. These processes include endocrine and neural signaling.	78.4%	20.6%	1%
I**nterdependence**: Cells, tissues, organs, and organ systems interact with one another (are dependent on the function of one another) to sustain life.	69.1%	27.8%	3.1%
Levels of organization: Understanding physiological functions requires understanding the behavior at every level of organization from the molecular to the social.	64.2%	32.6%	3.2%
Energy: The life of the organism requires the constant expenditure of energy. The acquisition, transformation, and transportation of energy is a crucial function of the body.	55.8%	41.1%	3.2%
Scientific reasoning: Physiology is a science. Our understanding of the functions of the body arises from	45.8%	43.8%	10.4%

the application of the scientific method; thus, our understanding is always tentative.			
Physics/chemistry: The functions of living organisms are explainable by the application of the laws of physics and chemistry.	39.6%	49.0%	11.5%
Cell theory: All cells making up the organism have the same DNA. Cells have many common functions but also many specialized functions that are required by the organism.	33.3%	54.2%	12.5%
Causality: Living organisms are causal mechanisms (machines) whose functions are explainable by a description of the cause-and-effect relationships that are present.	43.2%	33.7%	23.2%
Mass balance: The contents of any system or compartment in a system is determined by the inputs to and the outputs from that system or compartment.	37.9%	37.9%	24.2%
Genes to proteins: The genes (DNA) of every organism code for the synthesis of proteins (including enzymes). The functions of every cell are determined by the genes that are expressed.	24.0%	55.2%	20.8%
Evolution: The mechanisms of evolution act at many levels of organization and result in adaptive changes that have produced the extant relationships between structure and function.	19.0%	44.2%	36.8%

Discussion

Instructors cite multiple resources when developing physiology courses, but have relatively low knowledge of the physiology core concepts as a resource

Our work provides insight on several aspects of undergraduate physiology courses. First, our study provides more information on what resources instructors use to choose their list of topics when teaching a physiology course for the first time. Our results indicate that textbooks remain the most common resource used. The choice of textbooks has been shown to have large impacts on student learning in STEM courses (24, 25), and has also been cited as an important part of many college physiology classrooms (26, 27). While there have been calls advocating for alternates to textbooks in physiology and biology (28, 29), our results demonstrate that textbooks still hold a key role in shaping the choice of topics covered in physiology courses. Interestingly, the original development of the physiology core concepts was sparked partially by acknowledgement of a "knowledge explosion" in physiology that has contributed to the lengthening of textbooks. This increase in knowledge and corresponding increases in content in textbooks helped spark the development of the core concepts as a way to reduce and streamline key principles for physiology (5, 12). Though our survey did not explore if instructors utilize textbooks as a student-facing resource in their courses (or only used textbooks as a reference when designing the syllabus), these results indicate that there needs to be further study on how instructors reduce and synthesize the list of topics in physiology textbooks to design their courses. This is of particular importance given that textbooks have different levels of coverage for each of the physiology core concepts, with often inconsistent and even incorrect descriptions of some of the core concepts (5, 30). However, several textbooks have recently adapted the physiology core concepts as a framework for introducing material and used these core concepts as unifying themes throughout the text (15), suggesting that the physiology core concepts may be helping drive curricular decisions, even if instructors are not directly familiar with the idea of the core concepts.

The next most commonly cited resources for instructors choosing topics were past syllabi and colleagues both within and outside the institution. This aligns with past work that has identified how individual faculty can serve as important resources for colleagues teaching a course for the first time or looking to implement pedagogical change (31, 32). Similarly, instructors are often encouraged to examine past syllabi of the course and other related courses when developing new courses (33). In addition, relatively few instructors cited the use of either the physiology core concepts or any of the concepts or competencies from *Vision & Change*. Indeed, nearly 40% of surveyed instructors indicated that they had never heard of the physiology core concepts, with another fourth of instructors only minimally familiar with the core concepts. While there is a growing number of articles demonstrating the use of the physiology core concepts in creating new activities and assessments and shaping pedagogical approaches (12, 34), our results suggest that the influence of the physiology core concepts may be uneven and that the core concepts may not have permeated to a majority of physiology instructors yet. Future work can illuminate how instructors become familiar with the physiology core concepts. Our results also suggest a need to create and disseminate more accessible guides for instructors on ways that the core concepts can be used to refine course and program-level curricular decisions.

Multiple factors shape changes in the curriculum when a physiology course is repeated

In addition to examining what resources instructors use when designing a physiology course for the first time, we also queried instructors about what, if anything, led to the addition or removal of topics when a course was repeated in future terms. Past work has focused on examining changes in instructors' teaching approaches when repeating biology and physiology courses (35–37), but we are not aware of any past work that has examined what motivates instructors to make content or topical changes in a course over time. Our results indicate that the most frequently reported change was not a direct addition or removal of topic, but instead a shift in thematic focus or organization of the course. Responses included instructors who cited changing from an approach that described each organ system to one that focused on interconnected themes between systems, as well as instructors who highlighted the use of the core concepts in re-organizing the themes in their course. Similarly, approximately 10% of respondents also cited the use of the physiology core concepts, learning objectives published by HAPS (23), or other published list of topics or objectives as a factor in changing their course. However, responses in these categories were broad, and more work is needed to investigate these changes, the thematic approaches used in undergraduate physiology courses, as well as what factors influenced instructors to make these changes.

The second most commonly cited reason for changing course content was instructors indicating that that they removed topics in order to allow more time for active learning and to focus on the other existing concepts. Using evidence-based practices can take more instructional time as compared to didactic lectures (38), and our results indicate that physiology instructors who are implementing such approaches are making adjustments to their list of topics. Future work is needed to explore these instructors' motivations more in depth. For instance, some instructors may be driven by assessment data that indicates a need to dedicate more time on given topics, while other instructors may be inspired to incorporate additional activities to provide more in-depth coverage of a given concept. Similarly, nearly 10% of instructors also cited removing topics simply for the sake of time, mentioning how they felt like they were overambitious in the first iteration of the course and felt time pressure to cover their intended content. These results indicate that instructors in our study are gravitating toward reducing content in order to focus more instructional time on the remaining content. Given these results, physiology instructors may benefit from additional resources, such as mentorship from experienced instructors, that provide guidance on estimated pace and coverage for their physiology courses.

Intriguingly, the only reason that instructors cited for adding new content was due to new scientific advancements in physiology, suggesting that instructors rarely add new concepts unless there have been new research and knowledge in the field. The physiology core concepts were developed in response to this increasing amount of physiology knowledge, and have been acknowledged as a dynamic list of core concepts that may be adjusted with new knowledge in physiology (5, 12, 34). Our results thus support the idea that new scientific advances and research in physiology are directly impacting classroom instruction, with instructors adjusting their curriculum to cover new ideas and concepts. Our results also indicate that the physiology core concepts may need to be adjusted in the future as more knowledge is generated about physiology.

There remains uneven coverage of physiology core concepts and a need to increase teaching of certain core concepts

We examined the extent to which each of the physiology core concepts are taught in undergraduate physiology courses. Our results largely align with past work that has examined both faculty and student perceptions of the core concepts, as well as work that has investigated the extent to which undergraduate physiology programs cover each of the core concepts (12, 16, 17, 34) (Table 3). For instance, our results indicated that there are five core concepts with nearly universal coverage in the physiology courses reported by our respondents (Table 2). Instructors indicated that homeostasis, structure/function, flow down gradients, cell membrane, and cell-cell communications are taught in nearly all undergraduate physiology courses, with 1% or fewer of respondents indicating that these concepts are not taught in their courses. Similarly, nearly 80% or more of instructors stated that these core concepts were taught in significant detail in their physiology course. These results are largely similar to a survey of physiology instructors at seven institutions with physiology degree programs (16), which identified three of the same core concepts (homeostasis, structure/function, and cell-cell communication) as nearly universal across the programs' curriculum. The remaining two core concepts identified in our survey as widespread (flow down gradients and cell membrane), in contrast, were lower ranked in the survey of these physiology programs. More work is needed to examine why there appears to be a difference in reported coverage of these two core concepts. It is possible that the differences arise due to the different sampling schemes used: our work surveyed faculty across at least 91 different institutions, capturing a breadth of instructor responses but likely not investigating multiple physiology courses at one institution, while Stanescu et al. (2020) (16) instead provided an in-depth survey across all physiology courses in a limited number of physiology degree programs. Our work was also open to instructors of any physiology courses, and nearly 10% of respondents taught non-majors physiology. In contrast, Stanescu et al. (2020) (16) excluded physiology courses geared specifically for non-physiology majors given the focus on examining coverage in undergraduate physiology degree programs.

There was also substantial agreement for which core concepts are least covered between our survey and the results from surveying the curriculum across the seven physiology degree programs (16). Our survey indicated that mass balance, genes to protein, and evolution had the least coverage, with fewer than 40% of instructors indicating that they covered those concepts in significant detail (Table 2). Over a third of instructors stated that they did not cover evolution, the least covered core concept, with 45% only providing minimal coverage. Similarly, one fifth and one fourth of instructors stated that they did not cover genes to protein or mass balance, respectively. Genes to protein and evolution were similarly the least covered core concepts in the seven undergraduate physiology degree programs, with mass balance representing a poorly covered core concept as well (Table 3).

The extent that each core concept is covered in a physiology course or across a physiology curriculum likely impacts student learning of that core concept and their ability to apply that knowledge in future courses. We thus situate our work by comparing our results to those of a recent survey of students enrolled in physiology courses and physiology degree programs (17). This other survey asked students to self-report the level to which they perceived that they mastered each of the core concepts. While this measure does not capture an actual measure of student learning (which would require the use of concept inventories or other similar validated instruments), the survey provides a broad snapshot of student perspectives into their learning and physiology course experiences. Our survey data was also largely aligned with these student perceptions (Table 3). For instance, homeostasis and structure/function were the two most commonly covered core concepts, and also similarly represented the two core concepts where students perceived the most mastery. Cell membrane was the third most mastered core concept, as perceived by students, and was also likewise nearly universally covered in physiology courses, according to the instructors in our survey. Similarly, students perceived the lowest learning gains in genes to protein, evolution, causality, physics/chemistry, and mass balance, representing five of the six lowest covered core concepts identified in our survey.

Despite the variation in study populations, the alignment of our results with that of Stanescu et al. (2020) and Rogers et al. (2020) suggests that there are differences in how well covered each core concept is both within physiology degree programs and across a broader set of physiology courses. Taken together, these results indicate that there is an urgent need to examine why some core concepts appear to be not covered or covered in minimal detail across physiology courses and physiology degree program curriculum, and to develop resources to support the broader implementation of modules aligned with these core concepts. We speculate that the uneven coverage may be driven by multiple factors. For instance, while we found no differences in coverage of core concepts based on course level (non-majors; introductory; or mid- to upper-level courses), it is possible that the target student audience of a course may influence which core concepts are covered. An instructor may choose to cover a different set of core concepts for a required course for physiology majors as compared to an elective course on a specific topic within physiology for general biology majors, leading to potentially uneven coverage of concepts across the curriculum. In addition, we note that these differences may be driven by instructor familiarity with and perceptions of each of the core concepts. For instance, it is possible that physiology instructors may view a given core concept as more advanced than others, given their past background and experiences, and may be less likely to include coverage of these core concepts in more introductory-level courses. It is also possible that there is an asymmetrical distribution of resources to support teaching of these core concepts, with potentially more activities and modules available that align with some core concepts than others. Further work is needed to investigate the reasons behind these differences in coverage and if there are any systematic biases in when concepts are introduced to students.

Table 3. Comparison of faculty and student perceptions of the core concepts across different studies. The first column provides the rank order of the core concepts from most covered to least covered in physiology courses, based on our 2022 survey of physiology instructors who represent at least 91 different institutions. The second column indicates faculty coverage of core concepts across 7 undergraduate physiology degree programs in 2020 (16). The third column indicates results from a 2019 survey that reached nearly 1,400 students enrolled in physiology courses or physiology programs, capturing student perceptions of their mastery of each of the core concepts (17). Some ranks are repeated due to ties in this column.

Core concept	**Our work (survey of faculty across institutions), indicating coverage of core concepts in courses**	**Survey of faculty at 7 physiology degree programs** (16)**, indicating coverage of core concepts in courses**	**Survey of undergraduate physiology students indicated reported mastery of core concepts** (17)
Homeostasis	1	3	1
Structure/function	2	2	2
Flow down gradients	3	9	7
Cell membrane	4	11	3
Cell-cell communications	5	5	9
Interdependence	6	1	6
Levels of organization	7	10	10
Energy	8	7	5
Scientific reasoning	9	4	8
Physics/chemistry	10	8	14
Cell theory	11	13	3
Causality	12	6	13
Mass balance	13	12	14
Genes to proteins	14	14	11
Evolution	15	15	12

Limitations

We acknowledge that our work is limited in several ways. First, our survey relies on instructors recruited from several email listservs. The results may not be representative of all physiology instructors. However, we expect our instructors, on average, to be more familiar with the physiology core concepts and APS resources than a true random subset of physiology instructors given that we recruited instructors from the APS Teaching Section, SABER, and PALM email listservs. Thus, there may be even lower levels of knowledge and familiarity with the physiology core concepts and APS resources among all physiology instructors. We also acknowledge that the instructors in our survey may be more familiar with and more likely to implement evidence-based practices such as active learning, suggesting that there may be a lower frequency of instructors making changes in their course due to implementing active learning in the general pool of physiology instructors. Similarly, our work relies on respondents self-reporting data from their courses. There may be biases in how instructors reply to the survey, and our survey may not fully capture the depth of resources used when instructors are developing courses. Future work that relies on analyses of syllabi and interviews of instructors can offer more complete snapshots of what core concepts are taught in physiology courses and how instructors decide upon these topics. Finally, we note that our survey asked instructors to reflect upon the physiology course that they taught most recently. We acknowledge that this may potentially bias the results. For instance, some universities may have a physiology course sequence that spans across more than one term and would likely cover different core concepts each term. Asking only about the most recently taught physiology course may not accurately capture the breadth of core concepts that may be covered through that sequence. Despite these limitations, our work provides the first study we are aware of to characterize the extent that the physiology core concepts are being taught across a breadth of undergraduate physiology courses (including courses both within and outside of undergraduate physiology degree programs). Similarly, our work provides a first exploration of the resources that physiology course instructors draw upon when choosing the topics for their courses and making instructional decisions on adding or removing concepts. Our results thus provide valuable insight for supporting physiology education reform efforts.

Implications for the physiology education community

Our work demonstrates several areas of growth and future work for the physiology education community:

- **Explore reasons for uneven coverage of physiology core concepts.** Our work aligns with past investigations of faculty and student perceptions of the core concepts, identifying that certain core concepts, such as evolution and genes to protein, are likely not covered in much depth across many undergraduate physiology courses and physiology programs. Future work is needed to determine the reasons for this uneven coverage in core concepts in the classroom, to explore the potential barriers preventing more coverage of each of these core concepts, and to assess the impacts on student mastery of key physiology learning objectives.

- **Develop resources that promote the physiology core concepts.** Our results show overall low levels of familiarity with the collection of physiology core concepts, with nearly two-thirds of undergraduate physiology instructors surveyed indicating that they had not heard of the core concepts or were only minimally familiar. We urge the physiology education community to continue its efforts at disseminating the physiology core concepts to instructors at a diversity of institutions.. We also similarly call on the undergraduate physiology education community to develop more resources, such as guides for instructors on how to use core concepts, as well as instructional modules and curriculum aligned with the core concepts. For instance, other professional societies, such as the American Society of Plant Biologists, have implemented small grants to promote development and dissemination of curricular guides aligned with society-developed learning objectives (39). It is possible that similar grants from APS and other physiology societies may be beneficial in generating and disseminating new curriculum for instructors aligned with these core concepts.

- **Increase professional development for instructors on evidence-based pedagogies.** Our results indicate that instructors are largely relying on local resources available and are making changes in their courses based primarily on their own experiences. As such, there may be demand for increased professional development opportunities for physiology course instructors on designing and modifying physiology courses using evidence-based practices. For instance, APS is a founding member society of the PALM Network, which provides mentoring on the use of active learning (40, 41). However, such mentoring likely only occurs after an instructor has designed their course and has chosen their list of topics, and such mentoring may not be long-term enough to allow guidance for the instructor to teach repeated iterations of the same course. Similarly, past efforts at pedagogical reform in the physiology classroom have focused primarily on implementing specific active learning modules and have not incorporated discussion of course design and list of topics (42). Physiology instructors may thus benefit from targeted professional development geared towards first-time instructors as they design their course, or towards instructors who will be teaching the same course again to reflect and adjust the course in a future term.

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