A PERSONAL VIEW | P-MIG Special Collection

Evaluation of core concepts of physiology in undergraduate physiology curricula: results from faculty and student surveys

Claudia I. Stanescu,1 Erica A. Wehrwein,2 Lisa C. Anderson,3 and Jennifer Rogers4

1Department of Physiology, University of Arizona, Tucson, Arizona; 2Department of Physiology, Michigan State University, East Lansing, Michigan; 3Department of Integrative Biology and Physiology, University of Minnesota, Minneapolis, Minnesota; and 4Department of Health and Human Physiology, University of Iowa, Iowa City, Iowa

Submitted 30 December 2019; accepted in final form 11 August 2020

INTRODUCTION

Physiology as an undergraduate degree does not currently have programmatic curricular guidelines, as do other STEM (Science, Technology, Engineering, Mathematics) disciplines (22). As such, one aim of the Physiology Majors Interest Group (P-MIG) is to coordinate collaboration among numerous stakeholders to establish disciplinary recommendations for undergraduate physiology programming. Such guidelines may aid the development of new undergraduate physiology programs and facilitate the program review process for established programs (6). Three key areas under consideration to include in program-level guidelines are disciplinary content, professional skills development, and advising resources.

For this reason, three committees were formed to begin the initial work in these areas: 1) Curriculum Committee; 2) Professional Skills Committee; and 3) Advising Committee. This study focused on the work done by the Curriculum Committee related to the inclusion of physiology-specific conceptual models, or “core concepts,” in programmatic guidelines for physiology and physiology-related undergraduate degree programs. This report is different from others, because it evaluated core concept use across a whole curriculum rather than within a particular course.

“Core concepts” are big ideas that have been tested, validated, and considered central to a given discipline (5, 17). The use of core concepts or big ideas within a discipline has been emphasized in Vision and Change (1) and other publications (9, 10, 12, 14, 17, 23) as a way to form an enduring understanding of ideas that students could use beyond a particular course (7). Core concepts are important for teaching and learning because they provide cognitive scaffolds that integrate definitions of concepts, relationships between variables, and assumptions on which concepts are based. For example, physiology students are frequently asked to learn new vocabulary; learn new details about physiology; incorporate the new details into their prior knowledge of chemistry, biology, and physics; and then use that new vocabulary and knowledge to explain physiological mechanisms. Physiology is particularly challenging because students must perform all of these cognitive tasks simultaneously. Core concepts and their conceptual frameworks provide the scaffolding to manage the cognitive load.

The core concepts of physiology (13) were developed to encourage students to build conceptual understanding of physiology that allows them to problem solve, analyze, and apply their knowledge to new problems rather than simply acquire factual information (7). A review of the development of the core concepts of physiology and the development of conceptual frameworks or “unpacking” of selected core concepts is available in this special edition (7). When considering use of core concepts of physiology in undergraduate physiology, it is important to clarify faculty use of core concepts within individual courses versus incorporation of core concepts throughout curricular coursework. The core concepts of physiology...
were developed to aid learning within a single course, as well as to facilitate knowledge transfer across the breadth of a physiology curriculum.

Previous results published by Michael and McFarland (11) revealed homeostasis, interdependence, cell-cell communication, cell membrane, and flow down gradients were the top five core concepts that faculty in their sample determined as most important for students to understand. It is furthermore important to collect data about which core concepts are taught by faculty in their courses and across all courses within a curriculum, as opposed to gathering opinions regarding the importance of each core concept. The rationale of this approach is that determining what core concepts are currently taught across undergraduate physiology programs is essential information for the development of programmatic guidelines.

The purpose of this study was twofold. First, we aimed to develop a curriculum survey tool to evaluate use of the core concepts of physiology within courses across a curriculum. Second, we aimed to determine whether a subset of the 15 core concepts of physiology is commonly taught across numerous physiology undergraduate programs. We hypothesized that a subset of core concepts of physiology would emerge from the results of the curricular survey that could be compared with P-MIG survey results from individual faculty and results from previously published faculty and student surveys (11). If so, this subset of core concepts may form the basis for program-level undergraduate physiology curricular recommendations.

METHODS

Core Concepts Curricular Survey

The curricular survey (Table 1) was administered to faculty at seven self-selected institutions with physiology degree programs (see Supplemental Table S1 for a list of institutions; see https://doi.org/10.6084/m9.figshare.12761990.v1). The survey was administered by a volunteer faculty at each institution to all faculty who teach a course and/or part of a course in their program. Paper or electronic copies of the curriculum survey tool were provided to all faculty within a curriculum, as opposed to gathering opinions regarding the importance of each core concept. The rationale of this approach is that determining what core concepts are currently taught across undergraduate physiology programs is essential information for the development of programmatic guidelines.

The purpose of this study was twofold. First, we aimed to develop a curriculum survey tool to evaluate use of the core concepts of physiology within courses across a curriculum. Second, we aimed to determine whether a subset of the 15 core concepts of physiology is commonly taught across numerous physiology undergraduate programs. We hypothesized that a subset of core concepts of physiology would emerge from the results of the curricular survey that could be compared with P-MIG survey results from individual faculty and results from previously published faculty and student surveys (11). If so, this subset of core concepts may form the basis for program-level undergraduate physiology curricular recommendations.

Table 1. Curriculum survey tool administered to all faculty teaching courses in physiology programs at each participating institution

| Concepts from Core Principles of Physiology |
|--------------------------------------------|
| 1. Causality                               |
| Living organisms are causal mechanisms (“machines”) whose functions are explainable by a description of the cause-and-effect relationships that are present. |
| 2. Cell-cell communication                  |
| The function of the organism requires that cells pass information to one another to coordinate their activities. These processes include endocrine and neural signaling. |
| 3. Cell membrane                           |
| Plasma membranes are complex structures that determine what substances leave/enter cell. They are essential for cell signaling, transport, etc. |
| 4. 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. |
| 5. Energy                                  |
| The life of the organism requires the constant expenditure of energy. The acquisition, transformation, and transportation of energy are essential functions of the body. |
| 6. 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. |
| 7. Flow down gradients                     |
| The transport of “stuff” (ions, molecules, blood, and gas) is a central process at all levels of organization in the organism, and a simple model describes such transport. |
| 8. Genes to proteins                       |
| The genes (DNA) of every organism code for the synthesis of proteins (including enzymes). The genes that are expressed determine the functions of every cell. |
| 9. Homeostasis                             |
| The internal environment of the organism is actively maintained constant by the function of cells, tissues, and organs organized into negative feedback systems. |
| 10. Interdependence                        |
| Cells, tissues, organs, and organ systems interact with one another (are dependent on the function of one another) to sustain life. |
| 11. Levels of organization                 |
| An understanding of physiological functions requires understanding the behavior at every level of organization from the molecular to the social. |
| 12. Mass balance                           |
| The quantity of “stuff” in any system, or in a compartment in a system, is determined by the inputs to and the outputs from that system or compartment. |
| 13. Physics/chemistry                      |
| The functions of living organisms are explainable by the application of the laws of physics and chemistry. |
| 14. Scientific reasoning                   |
| Physiology is a science. Our understanding of the functions of the body arises from the application of the scientific method; thus our understanding is always tentative. |
| 15. 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. |

See Michael et al. (13). Faculty were asked to rate the core concepts of physiology according to the following scale: 0 = concept not included in my course; 1 = students are only minimally exposed to this concept; and 2 = students are exposed to this concept in significant detail.

were determined, and the percentage of courses that covered each core concept to any extent (1 = students are minimally exposed to concept, and 2 = students are exposed to concept in significant detail) at each institution was calculated. The University of Arizona Institutional

Advances in Physiology Education • doi:10.1152/advan.00187.2019 • http://advan.physiology.org
### Table 2: Sample curriculum summary that was to be completed by a faculty volunteer at each institution

| Level of Organization | Cell-Cell Interdependence | Homeostasis | Energy Balance | Communication | Reasoning  | Organization | Interdependence | Physics/Scientific Reasoning | Balance | Mass Transport | Cell Membrane | Cell Theory | Membrane Evolution | Genes to Proteins | Averages
|----------------------|---------------------------|-------------|----------------|---------------|------------|--------------|------------------|----------------------------|---------|----------------|--------------|-------------|-------------------|-----------------|---------|
| Structure/Function   |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Membrane Evolution   |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Cell Theory          |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Cell Membrane        |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Mass Transport       |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Homeostasis          |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Energy Balance       |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Communication        |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Reasoning            |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Organization         |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Interdependence      |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Physics/Scientific Reasoning |       |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Balance              |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Communication        |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Reasoning            |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Organization         |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Interdependence      |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Physics/Scientific Reasoning |       |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Balance              |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Communication        |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Reasoning            |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Organization         |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |
| Interdependence      |                           |             |                |               |            |              |                  |                            |         |                |              |             |                   |                 |         |

### RESULTS

**Core Concepts Curricular Survey**

Program characteristics, including institution name, size, degree name, and program size for the seven participating institutions in the 2019 curricular survey, are summarized in Supplemental Table S1. Courses offered at each institution and included in the survey are included in Supplemental Table S2 (see https://doi.org/10.6084/m9.figshare.12761999.v1). The core concept rank order showed substantial diversity from one institution to another without any apparent consensus across institutions.
on the top five core concepts, with the exception of homeostasis, which appeared in the top five for six out of the seven institutions.

The linear mixed model measuring the fixed effects showed that the core concept rankings were significantly different from each other \((P < 0.05)\). Nonparametric post hoc test for Friedman analysis revealed significant differences between pairs of core concepts (Fig. 1). Random-effects measurements showed that there is little variability (1.4\%) in core concept rankings (nonsignificant at \(P = 0.073\)) that is explained by the institution. Reliability statistics using intraclass correlations coefficients were used to determine whether the institutions are consistent in the way they ranked the core concepts. Intraclass correlation score (0.88) showed very good correlation between the institutions. These results were confirmed using nonparametric statistics (Friedman test and Spearman rank correlation). Overall, these results support combining the core concept rank data from all institutions to determine mean rank and standard errors.

When all core concepts were combined across all institutions (Fig. 1), the core concepts mean rankings (range 0–2 with 0 = concept not covered in course, 1 = students are minimally exposed to concept, and 2 = students are exposed to concept in significant detail) were as follows: 1) interdependence (1.47 ± 0.63); 2) structure/function (1.46 ± 0.72); 3) homeostasis (1.45 ± 0.71); 4) scientific reasoning (1.44 ± 0.70); and 5) cell-cell communication (1.38 ± 0.75). Evaluating the frequency at which the above core concepts appeared in the top five, rather than combined mean rankings, the following results were obtained: interdependence appeared in the top five at all seven institutions; structure/function, homeostasis, and scientific reasoning appeared in the top five at six institutions; cell-cell communication appeared in the top five at three institutions.

The curricular survey results also revealed which core concepts were least emphasized across these seven curricula. Based on the combined mean rankings, the least covered core concepts in physiology curricula shown in Fig. 1 were evolution (0.70 ± 0.71), genes to proteins (0.76 ± 0.74), cell theory (0.80 ± 0.76), mass balance (0.99 ± 0.79), cell membrane (1.07 ± 0.80) and levels of organization (1.07 ± 0.81).

When comparing the mean rankings for lower division courses \((n = 17)\) to the upper division courses \((n = 97)\), all core concepts had higher mean rank scores in upper division courses compared with lower division courses. However, the only core concept that was ranked significantly higher \((P = 0.043)\) in upper division courses was “genes to proteins.” “Physics and chemistry” approached significance at \(P = 0.069\).

Importantly, the curricular survey revealed that not all core concepts were covered in each individual course; however, all core concepts were covered to some extent across the curriculum for all participating institutions. Although some core concepts received a low ranking, all concepts were still covered in some of the courses in the curricula (Fig. 2).

**P-MIG Faculty Surveys**

The 2017 P-MIG faculty survey asked respondents to list the top five core concepts important for their programs and student demographics (Fig. 3). The core concepts most frequently reported within the top five were as follows: 1) homeostasis (selected by 84\% of 26 respondents), 2) structure function (81\%), 3) cell-cell communication (50\%); 4) scientific reasoning (46\%); and 5) levels of organization (42\%). In 2018 (Fig. 3), the top four ranked responses were the same as in 2017: 1) homeostasis (selected by 88\% of 16 respondents); 2) structure function (69\%); 3) cell-cell communication (56\%); and 4) scientific reasoning (44\%). The fifth ranked response was a three-way tie between energy, flow down gradients, and interdependence (38\%).

![Fig. 1. Mean rank for all core concepts combined across all seven institutions graphed in order of rank. Nos. in parentheses indicate the rank order for each core concept across all participating programs. The error bars represent 95% confidence interval. Some core concept rankings were significantly different from each other \((P < 0.05)\). *Core concepts by rank number (top) are significantly different \((P < 0.05)\) from the core concept plotted. For example, concept ranked no. 1 (Interdependence) is significantly different from concepts 6–15, but not significantly different from concepts 2–5.*](http://advan.physiology.org)
Comparison of Survey Results

We next compared the results of the curricular survey, the 2017 and 2018 P-MIG faculty surveys, and faculty and student survey results previously collected and reported elsewhere (11, 18) to determine whether a consensus finding of top core concepts of physiology would emerge (Table 3).

We included five total surveys and compared answers from six different survey questions from these surveys. Two questions were included from the student survey. This comparison illustrates homeostasis as the only core concept that appears in the top five for all faculty and student survey included in this study. Three core concepts included homeostasis (6 out of 6 survey questions), structure/function (5 out of 6 survey questions), and cell-cell communication (4 out of 6 survey questions).

Five additional core concepts, cell membrane, energy, flow down gradients, interdependence, and scientific reasoning, appeared in one-half of the survey questions included in this study (3 out of 6 survey questions). This points to the diversity in program emphases across various undergraduate physiology degree programs and supports the inclusion of many core concepts rather than a specific subset of core concepts in a physiology curriculum. When considering only the faculty surveys, there was broader consensus on certain core concepts. Homeostasis, cell-cell communication, interdependence, scientific reasoning, structure/function, and flow down gradients appeared among the top five in one-half or more of the faculty surveys. Three core concepts (cell-cell communication, interdependence, scientific reasoning) rated highly by faculty were not reflected in the top five core concepts reported by students.

| Institution                        | Homeostasis | Cell Membrane | Cell Biology | Cell-cell Communication | Energy | Evolution | Flow down Gradients | Gases to Gasses | Homeostasis | Interdependence | Levels of Organization | Mass balance | Physics/Chemistry | Scientific Reasoning | Structure/Function |
|------------------------------------|-------------|---------------|--------------|-------------------------|--------|-----------|---------------------|-----------------|-------------|------------------|---------------------|--------------|-------------------|---------------------|---------------------|
| Gonzaga University (N=11)         | 91%         | 55%           | 45%          | 64%                     | 82%    | 73%       | 45%                 | 36%             | 64%         | 82%              | 73%                 | 55%          | 64%               | 82%                 | 82%                 |
| Monash University (N=9)            | 100%        | 89%           | 56%          | 100%                    | 67%    | 78%       | 67%                 | 67%             | 100%        | 67%              | 67%                 | 67%          | 67%               | 100%                | 100%                |
| University of Arizona (N=21)       | 95%         | 86%           | 76%          | 90%                     | 81%    | 81%       | 67%                 | 67%             | 95%         | 100%             | 100%                | 81%          | 81%               | 100%                | 100%                |
| University of Iowa (N=21)          | 86%         | 67%           | 71%          | 81%                     | 76%    | 52%       | 67%                 | 52%             | 86%         | 95%              | 71%                 | 71%          | 81%               | 90%                 | 76%                 |
| University of Minnesota (N=13)     | 54%         | 92%           | 31%          | 92%                     | 85%    | 8%        | 92%                 | 77%             | 92%         | 92%              | 54%                 | 92%          | 85%               | 69%                 | 92%                 |
| University of Oregon (N=22)        | 55%         | 77%           | 64%          | 91%                     | 77%    | 64%       | 73%                 | 73%             | 91%         | 91%              | 68%                 | 64%          | 73%               | 86%                 | 91%                 |
| West Virginia University (N=17)    | 65%         | 41%           | 59%          | 65%                     | 88%    | 35%       | 53%                 | 41%             | 76%         | 82%              | 53%                 | 53%          | 65%               | 88%                 | 71%                 |

Fig. 2. Heat map representing the percentage of courses in a curriculum covering each core concept at each institution to any extent (1 = students are minimally exposed to concept, and 2 = students are exposed to concept in significant detail). Color representation is as follows: red = 80–100%, orange = 60–79%, yellow = 40–59%, green = 20–39%, blue 0–19%. N, no. of courses per institution for which core concept data were reported.

Fig. 3. Core concept rankings from 2017 and 2018 Physiology Majors Interest Group conference participants. Participants were asked, “For your program goals and for your student population, choose the TOP 5 most important core concepts (select only 5 from this list of 15 options).”
The core concepts of physiology were developed (13) to allow students to cultivate conceptual understanding of physiology and facilitate knowledge transfer across a course, as well as across all coursework completed within a physiology curriculum. The purpose of this study was to inform the P-MIG Curriculum Committee on the use of core concepts in physiology curricula for development of programmatic guidelines for physiology programs. This study did not focus on individual course objectives and instead collected data from a curricular perspective. With the overall goal to set program-level curricular guidelines for physiology degree programs at the undergraduate level, we desired to center these curricular guidelines on the published core concepts of physiology (13). From the 15 core concepts of physiology, we sought to determine whether a subset of core concepts is most commonly taught in undergraduate physiology curricula as a foundation for guidelines development. Our goal also included comparing the curricular survey results with results from other published faculty and student surveys to find a consensus set of core concepts to be included in program-level curricular guidelines.

Data from the curricular survey analyzed as a combined set, irrespective of institution, provide the following rankings for core concepts of physiology taught within seven self-selected undergraduate physiology programs: 1) interdependence; 2) structure/function; 3) homeostasis; 4) scientific reasoning; and 5) cell-cell communication. When comparing the top core concepts in all surveys included in the study, three core concepts were frequently reported by students and faculty as holding prominence in undergraduate physiology coursework. These concepts include homeostasis, structure/function, and cell-cell communication. Despite the appearance of an emerging subset of three core concepts from these surveys, there was considerable diversity of rankings among institutions. Therefore, the overall conclusion is that there is some support for inclusion of homeostasis, structure/function, and cell-cell communication in physiology curricula; however, there is no clear consensus, given the fact that these three core concepts did not rank in the top five at all institutions included in the survey (Table 3). This is consistent with the recommendations of Michael and McFarland (11) specifically that the core concepts are not intended to be a comprehensive list of topics to be addressed in a physiology curriculum, but a framework to guide the curriculum of a physiology program, depending on the programmatic emphasis of a given institution.

Despite the lack of consensus on the top five core concepts, one core concept, homeostasis, was marked as important in all surveys and appeared in the top five for six out of the seven institutions surveyed. This is not surprising, as homeostasis is a central concept in physiology built on the concept of the internal milieu (4) and the concept of an appropriate response to a given stimulus (3). Through the conceptual framework of homeostasis, a physiologist can convey ideas about the cellular environment, parts of a feedback mechanism, and types of regulation (negative feedback, positive feedback, feed forward, pattern generators, etc.) (8, 15). The conceptual framework for homeostasis provides a means for helping students learn concepts, use their knowledge to explain physiological processes, and predict outcomes in novel situations, which is the higher level thinking we want our students to master. Not surprisingly, homeostasis was the second core concept that was “unpacked” to describe the conceptual framework (8). Although we are not recommending a specific subset of core concepts to be included in physiology curricula, based on our results, we suspect that the concept of homeostasis will likely be included in program learning outcomes at many institutions.

The curricular survey also brought to light the core concepts that are covered the least in these seven physiology programs. These core concepts were evolution, genes to proteins, cell theory, cell membrane, and mass balance. Why is there such variability in the teaching of core concepts in physiology courses? First, departmental coursework in physiology programs may focus less on evolution, cell theory, and genes to proteins, and instead rely on courses from other departments to cover this content; for example, evolution and cell theory may be addressed in required prerequisite coursework from biology, whereas mass balance is covered in required prerequisite course work in chemistry. These prerequisite courses were not assessed with this particular curriculum survey. Second, the lower rankings for these core concepts also reflect that many
Physiology degrees tend to focus more on human and systems level coursework, which aligns well with student interests, as shown in previously published surveys (21). Furthermore, a lower survey rating for a concept does not indicate that a particular core concept is “less important” or should not be included in programmatic guidelines for undergraduate physiology curricula. Figure 2 illustrates the percentage of courses that include each core concept, and, although some core concepts are rated lower than others, the percentage of courses that include that concept is relatively high across the seven institutions. For example, at the University of Iowa, evolution is the lowest ranking core concept but is still included to some degree in >50% of departmental courses.

One interesting finding of this study was that the curricular survey administered to faculty led to a different set of core concepts that appeared in the top five compared with the concepts that students stated that they “mastered” or “will remember in 5 years” (18). Three core concepts (cell-cell communication, interdependence, scientific reasoning) were highly ranked by faculty and did not appear in the top five in the student survey responses. One explanation for the differences in findings between faculty and students is that the curricular survey and student survey were administered at different institutions that presumably have a different focus in their programs. Our study found that there was substantial diversity in focus and emphasis of core concepts among physiology programs at different institutions. Another explanation could be that the students were primarily second- and third-year students. Perhaps they had not yet taken advanced coursework that may emphasize different core concepts. In addition, the differences in results between faculty and students could also be explained by the focus of the questions posed to students. The student questions were focused on mastery of core concepts and prediction of whether they would remember a concept in 5 yr rather than on course coverage. It is possible that the concepts that students remember may be easier to understand or may have a special relevance to students, despite the coverage in a course. It is also possible that faculty are not sufficiently emphasizing these three core concepts to students. This illustrates the need to focus on assessment of core concepts in courses included in physiology curricula in future surveys rather than on faculty or student opinion of concept coverage or mastery. Future studies should quantify the use of core concepts by analyzing program- and course-level assessments to determine how often core concepts were incorporated into course exams and whether these core concepts corresponded with program-level assessments.

Based on the feedback collected and reported in the curriculum summary from each institution, the curricular survey can be a powerful tool to facilitate program-wide discussion related to curricular evaluation, curricular learning outcomes, and faculty self-reflection. The comments from faculty who completed the survey illustrate that the curricular survey can be used as a tool to stimulate faculty-wide discussion and self-reflection to improve the curriculum. Evaluation of core concept use within a program can prompt discussion about program outcomes and assessment. The survey can be used to evaluate undergraduate physiology programming at the local level. The survey is easy to administer and takes a few minutes to complete by individual faculty, and the results can be reported back to the group. This tool in connection to the future programmatic guidelines that P-MIG is working on developing can be used for curricular improvements, program review, and evaluation (6). A novel curriculum mapping database has been developed as an extension of the original paper surveys, allowing programs to digitally perform analysis of their courses (20).

Limitations

Limitations of this study include the lack of data on progressions through each curriculum, which did not allow for in-depth analyses of connections between core concepts in introductory or core courses compared with upper level advanced coursework. Future studies should separate core concept use in required major coursework versus all coursework in a degree program and include information about course sequencing, which would provide a better understanding of the progression through the curriculum. This would allow a program to determine how students accomplish program learning outcomes when taking different elective courses.

Summary and Conclusion

Based on the curriculum survey results and the comparison with results from faculty and student surveys, there are four primary findings. 1) The core concepts of physiology are robustly represented across physiology curricula. We found that all concepts are included in one or more courses within each program evaluated. This finding supports the inclusion of the core concepts in curricular guidelines for physiology and physiology-related programs. 2) Individual physiology programs show diversity in the core concepts of physiology emphasized across the curriculum. Our study did not find a subset of core concepts that were emphasized across all institutions, in contrast to our original hypothesis. However, three core concepts appeared in more than one-half of all included surveys: homeostasis, structure/function, and cell-cell communication. However, not all of these concepts appeared in the top five for all institutions included in the curricular survey. This finding supports the notion that programmatic guidelines should allow flexibility in emphasis of specific core concepts of physiology. 3) The core concepts were ranked higher in upper division courses compared with lower division courses, although only one of the core concepts was significantly higher (genes to proteins). This is consistent with the expectation that core concepts would be introduced in lower level courses and expanded upon in upper division courses. 4) The curriculum mapping activity described here may be a valuable tool to foster faculty discussions regarding undergraduate physiology programming and provide a preliminary curricular evaluation tool at the local level.

In conclusion, this study provides evidence that undergraduate physiology programs are broadly covering the core concepts of physiology, thus supporting the notion that core concepts and other general models of science teaching should be included in undergraduate physiology disciplinary guidelines. Our study found three core concepts that form the foundation of a consensus for programmatic guidelines, but the core concepts can and should be used differently by each institution, depending on their program goals. Our evidence points to the heterogeneous nature of physiology and physiology-related programs based on this sample of seven programs.
The physiology programmatic guidelines should allow for program diversity and support the emphasis of any subset of core concepts of physiology.

This paper is published as part of a special collection/special issue from P-MIG, a grassroots organization that has formed to help develop programmatic guidelines for undergraduate degrees in the discipline and to serve those engaged in undergraduate physiology or physiology-related programs. To find out more about this collective, or get involved, please visit our website (https://www.physiologymajors.org/) and consider joining our list serv.

ACKNOWLEDGMENTS

We thank the programs that participated in the curricular survey, the volunteer faculty who compiled the data for their institution, and the P-MIG participants who completed the faculty surveys. We also thank Mark Borgstrom for assistance with statistical analyses.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

C.I.S. conceived and designed research; C.I.S. performed experiments; C.I.S. analyzed data; C.I.S., E.A.W., L.C.A., and J.R. interpreted results of experiments; C.I.S. prepared figures; C.I.S., E.A.W., L.C.A., and J.R. edited and revised manuscript; C.I.S., E.A.W., L.C.A., and J.R. approved final version of manuscript.

REFERENCES

1. American Association for the Advancement of Science. Vision and Change in Undergraduate Biology Education: A Call to Action. Washington, DC: American Association for the Advancement of Science, 2011.
2. Anderson LC, Rogers J, Stanescu CI, French MB, VanRyn VS, Wehrwein EA. Physiology educators find community in the Physiology Majors Interest Group. Adv Physiol Educ. In press. doi:10.1152/advances.00018.2019.
3. Bernard C. Lecons sur les Phenomenes de la vie Communs aux Animaux and aux Vegetaux. Paris: Bailliere, 1878.
4. Cannon WB. Organization for physiological homeostasis. Physiol Rev 9: 399–431, 1929. doi:10.1152/physrev.1929.9.3.399.
5. Duschl RA, Schweingruber HA, Shouse AW (Editors). Taking Science to School: Learning and Teaching Science in Grades K–8. Washington, DC: National Academies Press, 2007.
6. Johnson KMS. Putting the guidelines to work: moving from physiology undergraduate curricular guidelines to program development and improvement. Adv Physiol Educ. In press. doi:10.1152/advances.00180.2019.
7. McFarland JL, Michael JA. Reflections on core concepts for undergraduate physiology programs. Adv Physiol Educ. In press. doi:10.1152/advances.00188.2019.
8. McFarland J, Wenderoth MP, Michael J, Cliff W, Wright A, Modell H. A conceptual framework for homeostasis: development and validation. Adv Physiol Educ 40: 213–222, 2016. doi:10.1152/advan.00103.2015.
9. Michael J, Cliff C, McFarland J, Modell H, Wright A. The Core Concepts of Physiology: A New Paradigm for Teaching Physiology. New York: Springer Nature, 2017.
10. Michael J, Martinkova P, McFarland J, Wright A, Cliff W, Modell H, Wenderoth MP. Validating a conceptual framework for the core concept of “cell-cell communication”. Adv Physiol Educ 41: 260–265, 2017. doi:10.1152/advan.00100.2016.
11. Michael J, McFarland J. The core principles (“big ideas”) of physiology: results of faculty surveys. Adv Physiol Educ 35: 336–341, 2011. doi:10.1152/advan.00004.2011.
12. Michael J, Modell H. A conceptual framework for the core concept of “cell membrane”. Adv Physiol Educ 43: 373–377, 2019. doi:10.1152/advan.00051.2019.
13. Michael J, Modell H, McFarland J, Cliff W. The “core principles” of physiology: what should students understand? Adv Physiol Educ 33: 10–16, 2009. doi:10.1152/advan.90139.2008.
14. Mitchell I, Keast S, Panizzon D, Mitchell J. Using ‘big ideas’ to enhance teaching and student learning. Teach Teach 23: 596–610, 2017. doi:10.1080/13540602.2016.1218328.
15. Modell H, Cliff W, Michael J, McFarland J, Wenderoth MP, Wright A. A physiologist’s view of homeostasis. Adv Physiol Educ 39: 259–266, 2015. doi:10.1152/advan.00107.2015.
16. Monash University. Monash at a Glance (Online). https://www.monash.edu/about/who/glance [20 Dec 2019].
17. Next Generation Science Standards. Next Generation Science Standards (Online). https://www.nextgenscience.org/ [20 Dec 2019].
18. Rogers J, McFarland JL, Stanescu CI, Crosswhite PL, Crecelius AR. The 2019 P-MIG student survey report and capturing the undergraduate perspective of physiology programming. Adv Physiol Educ. In press. doi:10.1152/advan.00189.2019.
19. Romaniuk BR (Editor). The College Blue Book: Degrees Offered by College and Subject (46th Ed.). Farmington Hills, MI: Macmillan Reference USA, 2019.
20. Shaltry C. A new model for organizing curriculum alignment initiatives. Adv Physiol Educ. In press. doi:10.1152/advan.00174.2019.
21. Steury MD, Pocheracki JM, Kelly KL, Wehrwein EA. Perspectives of physiology as a discipline from senior-level millennial-generation students. Adv Physiol Educ 39: 240–241, 2015. doi:10.1152/advan.00104.2014.
22. Wehrwein EA. Setting national guidelines for physiology undergraduate degree programs. Adv Physiol Educ 42: 1–4, 2018. doi:10.1152/advan.00051.2017.
23. Wiggins G, McTighe J. Understanding by Design. Upper Saddle River, NJ: Pearson Education, Inc, 2006.