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The core principles ("big ideas") of physiology: results of faculty surveys

Joel Michael[1] and Jenny McFarland[2]

[1]*Department of Molecular Biophysics and Physiology, Rush Medical College, Chicago, Illinois; and* [2]*Biology Department, Edmonds Community College, Lynnwood, Washington*

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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.—Physiology faculty members at a wide range of institutions (2-yr colleges to medical schools) were surveyed to determine what core principles of physiology they want their students to understand. From the results of the first survey, 15 core principles were described. In a second survey, respondents were asked to rank order these 15 core principles and, independently, to identify the three most important for their students to understand. The five most important core principles were "cell membrane," "homeostasis," "cell-to-cell communications," "interdependence," and "flow down gradients." We then "unpacked" the flow down gradients core principle into the component ideas of which it is comprised. This unpacking was sent to respondents who were asked to identify the importance of each of the component ideas. Respondents strongly agreed with the importance of the component ideas we had identified. We will be using the responses to our surveys as we begin the development of a conceptual assessment of physiology instrument (i.e., a concept inventory).

conceptual assessment; concept inventory

WHAT DO WE WANT physiology students to know and be able to do? Two recent reports by national committees, Vision and Change (1) and Scientific Foundations for Future Physicians (2), point to the need for students, our future physicians, scientists, and citizens, to understand and be able to use disciplinary core principles and not just memorize facts, equations, and processes.

However, this requires that we identify the core principles of physiology and that we develop assessments that will permit us to determine whether students understand and can apply these concepts. This article describes our efforts to involve a wide variety of physiology faculty members in identifying core principles in physiology. This is the first step in the development of an instrument, a concept inventory, to assess the conceptual understanding of physiological core principles.

Conceptual assessment is emerging as an important focus of science education research (3, 6–9, 11, 18, 19), and the development of "concept inventories" is a critical component of that work. Concept inventories are typically sets of multiple-choice questions that assess the understanding of core principles (concepts), as opposed to testing memorization of facts or ability to manipulate equations. The items that make up these inventories are also able to diagnose common student misconceptions. These instruments can be used for the formative assessment of student learning, for comparing different pedagogical approaches, and for program assessment. "Assessments that are designed to diagnose students' misconceptions can be powerful educational tools" (10).

Address for reprint requests and other correspondence: J. Michael, Dept. of Molecular Biophysics and Physiology, Rush Medical College, 1750 W. Harrison St., Chicago, IL 60612 (e-mail: jmichael@rush.edu).

Our work was prompted by three National Science Foundation-sponsored meetings on Conceptual Assessment in Biology (CAB) in March 2007 (CAB I; Refs. 7, 13, and 19), January 2008 (CAB II; Ref. 14), and May 2010 (CAB III). The participants at these meetings represented a broad range of biological sciences from biochemistry and molecular biology to physiology to ecology. After much discussion, there was general agreement at CAB I that eight core principles (see Table 1) were applicable to the biological sciences (13).

Michael et al. (15), building on the ideas set forth in the first two CAB meetings (and previous work on core principles, big ideas, and general models specific to physiology; Refs. 5 and 16) described nine core principles from the perspective of four physiology faculty members (J. Michael, H. Modell, J. McFarland, and W. Cliff) who teach physiology to diverse groups of students at different educational levels (two at medical schools, one at a liberal arts university, and one at a public community college). However, it appeared to us that these core principles differ considerably in their applicability to the teaching of physiology, with some seeming more important than others. Despite the diversity of the four authors, we could not be sure that this list included all the core principles that physiology faculty members want their students to understand. It was also not clear that our colleagues in the wider physiology teaching community share our view of the relative importance of each core principle.

Therefore, we (J. Michael and J. McFarland) sought to determine what the community of physiology teachers thought were the most important core principles of physiology by asking them directly.

Survey Methods

Participation in the first survey was solicited by an e-mail message posted to listservs sponsored by four different organizations: the Teaching Section of the American Physiological Society, the Human Anatomy and Physiology Society, the Northwest Biology Instructor's Organization, and the Teaching Commission of the International Union of Physiological Sciences. Those individuals who agreed to participate were directed to the URL of a web survey (SurveyMonkey.com). A total of 81 physiology faculty responded to our solicitation to participate. We do not know how many individuals subscribe to each of the listservs (and individuals may subscribe to more than one), nor do we know how many subscribers actually read our message. Thus, it was not possible to determine the response rate to our survey. However, the institutional and geographic diversity of the 81 respondents suggests that we

Table 1. *Core principles from the CAB I meeting*

Casual mechanisms
Ecosystems and environments
Evolution
Homeostasis
Information flow
Matter/energy transfer and transformation
Structure-function relationships
The cell

CAB, Conceptual Assessment in Biology. See Ref. 13.

have obtained a useful sampling of our colleagues (see Table 3).

The surveys were NOT anonymous. Respondents were asked to identify the institutions at which they teach, the nature of the program in which they teach, and their years of physiology teaching experience. Respondents to the second and third surveys were solicited by e-mail from the pool of respondents to the first survey.

Surveys were held open for 1 mo. Upon closing each survey, the accumulated results were downloaded into a spreadsheet for analysis.

The second and third surveys used Likert scales to obtain respondents' opinions about a set of questions. The analysis of data derived from Likert scales is a contentious issue (see Ref. 12 for a brief discussion of these issues). We simply calculated aggregate scores (the sum of responses from all respondents) by multiplying the ratings (values were 1–5) by the number of respondents who selected that rating.

Surveys

The first survey. The purpose of the initial survey was to ask our respondents to identify all of the core principles of physiology that they thought were important. This survey, conducted in November 2008, first offered respondents three definitions of "core principles" or "big ideas," which are reproduced in Table 2 (the terms "big ideas" and "core principles" are often used as synonyms). The survey then asked the respondents to "describe the big ideas that you would want your students to understand. You can write as much as you want, but there is some virtue in brevity (as long as your ideas are clear)." The survey allowed free text responses of any length.

Eighty-one physiology faculty members teaching at a variety of institutions (see Table 3) responded to this survey, and seventy-three of these responses answered the question with responses that could be interpreted as big ideas (some respondents left this field blank or listed what were obviously lecture titles or chapter headings). These 73 useable responses varied in length from a few words to 286 words, and there were 7 responses in excess of 150 words.

Table 3. *The faculty members responding to our surveys teach physiology at a variety of different kinds of academic institutions*

	First Survey	Second Survey	Third Survey
Total number of respondents	81	61	37
Types of institutions represented*			
A. 2-yr community college	24	17	11
B. 4-yr college granting only a BS/BA	5	5	1
C. 4-yr college or university granting a BS/BA degree and some graduate degrees	23	19	9
D. Research university	17	14	7
E. Professional school (medical/dental/nursing)	29	21	10

*Some faculty members teach in more than one type of institution and were therefore counted in more than one category.

Both authors independently read all surveys looking for descriptions of ideas and themes (core principles) that occurred in multiple responses. In the survey responses, some core principles were stated or described explicitly using language similar to that used in the CAB I report and frequently found in textbooks (for example, "homeostasis," "flow," or "evolution" were words used in responses). In other cases, some interpretation was needed to categorize a response. However, we endeavored to keep our interpretations as conservative as possible to avoid projecting our preconceived ideas into our respondents' replies.

For example, "Ohm's law and its permutations," "'stuff' flows down a gradient," "pressure-flow relationships," and similar survey responses were categorized as the core principle "flow down gradient."

On the other hand, extracting the core principle of "interdependence" from the survey responses required rather more interpretation. The following comments were received from eight different faculty respondents and are reproduced here exactly as worded:

- "Interrelatedness of the systems of the body"
- "Integration"
- "How does this (organ, system, etc) work with the other (organ, system, etc)?"
- "All physiological systems are interdependent"
- "All systems are interconnected"
- "Connections between systems, how one aspect can affect another"

Table 2. *Definitions of "big ideas" (core principles) included in first survey*

From Duschl et al. (4):
"Each [big idea] is well tested, validated, and absolutely central to the discipline. Each integrates many different findings and has exceptionally broad explanatory scope. Each is the source of coherence for many key concepts, principles and even other theories in the discipline."
From Niemi and Phelan (17):
". . . organized around central concepts or principles, or 'big ideas.' The nature of these concepts differs from domain to domain, but in general they are abstract principles that can be used to organize broad areas of knowledge and make inferences in the domain, as well as determining strategies for solving a wide range of problems."
From Wiggins and McTighe (20):
"By definition, big ideas are important and enduring. Big ideas are transferable beyond the scope of a particular unit . . . Big ideas are the building material of understanding. They can be thought of as the meaningful patterns that enable one to connect the dots of otherwise fragmented knowledge."

Table 4. *Core principles proposed by physiology faculty respondents*

Core Principle	Description	Rank	Top Five
Causality[1,3]	Living organisms are causal mechanisms (machines) whose functions are explainable by a description of the cause-and-effect relationships that are present.	14	
Cell-cell communications[2]	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	X
Cell membrane[2]	Plasma membranes are complex structures that determine what substances enter or leave the cell. They are essential for cell signaling, transport, and other processes.	1	X
Cell theory[1,3]	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.	9	
Energy[1,3]	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.	6	
Evolution[1,3]	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.	15	
Flow down gradients[2,3]	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.	5	X
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.	11	
Homeostasis[1–3]	The internal environment of the organism is actively maintained constant by the function of cells, tissues, and organs organized in negative feedback systems.	1	X
Interdependence	Cells, tissues, organs, and organ systems interact with one another (are dependent on the function of one another) to sustain life.	4	X
Levels of organization[3]	Understanding physiological functions requires understanding the behavior at every level of organization from the molecular to the social.	12	
Mass balance[2]	The contents of any system or 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.	10	
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.	8	
Structure/function[1,3]	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.	7	

Overlap of our core principles with those identified by others: [1]one of the big ideas identified at the CAB I meeting (13), [2]one of Modell's general models (16), or [3]one of the core principles detailed in Michael et al. (15).

- "Interplay of organs and systems and how they affect each other"
- "Systems are interdependent. Though we survey systems, it is important to stress the interconnections and interactions among systems"

Although we had not previously considered "interdependence" as a core concept in physiology, this clearly emerged as a core principle for many of the survey respondents.

Each author independently compiled a list of all of the core principles they had extracted from the survey responses. Comparison of the lists from both authors revealed nearly complete agreement between them. The authors easily arrived at a consensus regarding the set of principles articulated by diverse physiology faculty members (the survey respondents), and a list of 15 core principles was compiled from the survey responses. This list is shown in Table 4.

The list of core principles that physiology faculty members (survey respondents) described overlapped significantly with the list generated at the CAB I meeting (13) and with the list described by Michael et al. (15). In Table 4, we indicated which of the 15 core principles described by the survey respondents are also on the lists developed at the CAB I meeting (13) and which are similar to the general models (recurring themes) identified by Modell (16). There were also similarities to the list generated by Feder (5), whose approach to the question of what physiology students should learn was quite different. However, there were a number of proposed core principles that were either not on the list from the CAB I meeting or emerged in a different form, including "scientific reasoning," "cell membranes" (as a core principle separate from "cells"), and "interdependence."

The second survey. The purpose of the second survey was to assess the relative importance attached to each of the 15 core principles in physiology by the survey respondents. In the second survey (conducted in March 2009), the respondents to the first survey were asked to indicate their agreement with the statement that "this core principle is important for my students to understand" using a five-point Likert scale (where *1* = strongly disagree and *5* = strongly agree). They were separately asked to identify the three most important core principles in the list of 15. [The survey prompt was as follows: "Below are the 15 core principles we have been considering. Select the three (3) that you believe to be the most important for your students to understand by the end of your course."] Responses were obtained from 61 of the 81 respondents to the first survey. The respondents to the second survey continued to be a diverse group of faculty members teaching at different kinds of institutions (see Table 3).

The 61 responses to the second survey were analyzed, and the resulting rank order of these 15 core principles derived from the survey results is shown in Tables 4 and 5. Although we had asked respondents to identify the top three core principles, we have marked the top five core principles. We did this for two reasons: *1*) there was a tie for the top, most important, core principle, and *2*) *no. 4*, "interdependence," is not as well defined as the others, and it will, therefore, be hard to "unpack" and assess this core principle. Table 5 shows the distribution of responses among the five Likert ratings for each core principle.

Table 5. *Distribution of Likert ratings for each of the 15 core principles*

Core Principle	Rank	Top 5	Score 1	2	3	4	5
Cell membrane	1	X	0	1	2	10	48
Homeostasis	1	X	2	0	1	7	51
Cell-cell communications	3	X	0	0	3	16	42
Interdependence	4	X	0	2	5	14	40
Flow down gradients	5	X	1	1	3	19	37
Energy	6		0	2	7	17	35
Structure/function	7		3	1	4	20	33
Scientific reasoning	8		0	6	7	19	29
Cell theory	9		2	5	11	13	30
Physics/chemistry	10		1	3	16	21	20
Genes to proteins	11		2	6	12	15	26
Levels of organization	12		1	3	16	21	20
Mass balance	13		0	11	15	15	20
Causality	14		3	12	10	17	19
Evolution	15		9	8	18	9	17

Scores were as follows: *1* = strongly disagree and *5* = strongly agree.

We also analyzed the responses to determine whether there was a difference in the rank order proposed by faculty members identifying themselves as teaching at 2-yr community collegesand the other respondents teaching at 4-yr or graduate institutions. Table 6 shows the rank order of the top seven core principles. Although the absolute ordering was not identical, there was no clear difference of opinion about what is important for students to understand across the spectrum of faculty members teaching at different kinds of educational institutions.

Every core principle that has been identified is a "big idea" in that it encompasses many smaller component ideas. To be useful in an educational context (i.e., teaching, learning, and assessment), each of the core principles must be unpacked into its component ideas. For example, "resistance" is an important component idea within the core principle of "flow down gradients." Component ideas serve as vehicles for applying the core principles to specific areas of physiology at appropriate levels of complexity, thus matching expected learning outcomes and assessments. We have begun the process of unpacking the core principles by starting with one of the top five core principles identified by our respondents.

We started with the core principle of "flow down gradients." We picked this core principle for two reasons. Like our respondents, we deemed it to be an important core principle for students to understand. We also thought that it would be easiest of the five core principles for us to unpack. Our proposed unpacking of "flow down gradients" is shown in Table 7.

The third survey. The purpose of the third survey was to obtain feedback on our proposed unpacking of the "flow down gradients" core principle. The respondents to the second survey were contacted via e-mail and invited to participate in the third survey. In the third survey (conducted in January 2010), we asked respondents to indicate whether each of our proposed component ideas that we had unpacked from the core principle of "flow down gradients" was important for their students to understand, again using a five-point Likert scale. We also asked for suggestions, edits, and additions to the unpacking (and we received several). Thirty-nine of the respondents to the second survey responded to the third survey (see Table 3), but only thirty-seven responses contained usable data.

The results (see Table 7) suggest that our unpacking of this core principle is acceptable to the physiology faculty members who responded to our surveys. Written comments were re-

Table 6. *Comparison of the rankings of core principles by community college faculty members and all other faculty members*

Core Principle	Ranking	Core Principle	Ranking
Community college faculty members		All other faculty members	
Homeostasis	1	Cell membrane	1
Interdependence	2	Homeostasis	2
Cell-cell communications	2	Flow down gradients	3
Cell membrane	3	Cell-cell communications	3
Flow down gradients	4	Interdependence	4
Energy	4	Energy	5
Cell theory	4	Scientific reasoning	6

n = 17 community college faculty members and 44 faculty members from all other institutions.

Table 7. *In the third survey, for each item below, we asked faculty members to respond to the following question: "How important is it that your students understand this?"*

Flow Down Gradients	Sum of Ratings*
I. Flow is the movement of "stuff" from one point in a system to another point in the system.	174
A. Molecules and ions in solution move from one point to somewhere else.	172
B. Fluids (blood and chyme) and gases (air) move from one point to another.	154
C. Heat moves from one place to another.	131
II. Flow occurs because of the existence of an energy gradient between two points in the system.	174
A. Differences in concentration (concentration gradients) cause molecules and ions in solution to move toward a region of lower concentration.	177
B. Differences in electrical potential (potential gradients) cause ions in solution to move.	175
C. Differences in pressure (pressure gradients) between two points in a system cause substances to move toward a region of lower pressure.	173
D. Differences in temperature (temperature gradients) between two points cause heat to flow.	148
III. The magnitude of the flow is a direct function of the magnitude of the energy gradient that is present; the larger the gradient, the greater the flow.	171
IV. More than one gradient may determine the magnitude and direction of the flow.	167
A. Osmotic (concentration gradient) and hydrostatic pressures together determine flow across capillary walls.	170
B. Concentration gradients and electrical gradients determine ion flow through channels in cell membranes of neurons and muscle cells.	171
V. There is resistance or opposition to flow in all systems.	165
A. Resistance and flow are reciprocally related; the greater the resistance, the smaller the flow.	165
B. Resistance is determined by the physical properties of a system.	159
C. Some resistances are variable and can be actively controlled.	163
i. Ion channels in a membrane can open and close (increasing resistance).	168
ii. Arterioles and bronchioles can constrict and dilate.	171
iii. Piloerection can increase the resistance to heat flow in many mammals.	111

*The number of responses was 37; hence, the maximum possible sum was 185.

ceived from 30 of the 39 respondents. These comments were universally supportive of our unpacking; some contained minor suggestions for rewording, but the respondents did not suggest substantial changes our proposed unpacking. It is clear, however, that a few of the unpacked ideas, particularly those related to flow of heat down a temperature gradient, were not important to as many respondents as most of the others.

Discussion

We surveyed faculty members who teach physiology at a variety of 2- and 4-yr colleges, universities, and medical schools (Table 3) to determine their views about the core principles of physiology they want their students to understand (Table 4). We determined the relative importance of these core principles (Tables 4 and 5) to these survey respondents. We compared the rankings produced by community college faculty members to those produced by all other faculty members (Table 6). Finally, we unpacked one of the core principles thought to be most important into its component ideas and solicited ratings of the importance of these component ideas (Table 7).

We invited participation in this project using four different listservs to which physiology faculty members subscribe and on which many faculty members actively participate in discussions. We were gratified by, and indebted to, the many colleagues who responded to our request for participation. The diversity of this group makes us reasonably confident that our results reflect the thinking of the broader community of physiology faculty members.

There was considerable agreement among faculty members at different types of educational institutions about the most important core principles; comparing the responses from 2-yr college faculty and all others revealed no obvious meaningful differences. In addition, of the 81 responses to the first survey, there were 10 from institutions in foreign countries (England, Canada, The Netherlands, Belgium, Norway, Brazil, and Australia). The diversity of the faculty members responding to our surveys and the high levels of agreement in their responses support our hypothesis that there is a set of core principles that can be viewed as being central to the discipline of physiology and thus important for students to understand.

It was important for us to complete this survey before the Michael et al. report (15) was available to readers, so that this report would not influence the respondents to the survey. The CAB I list was already published (13), however, and this could have had an influence on some of the survey respondents, and although we attempted to be conservative in interpreting responses, our previous work and biases could have influenced our analysis.

There are several aspects of the responses we received from our respondents that deserve further comment. First, the core principles generated by physiology faculty members were very similar to those generated by a group of biologists from diverse subdisciplines (see the CAB I information shown in Table 4). It appears that there are similar core principles of physiology as a discipline that are obvious to physiologists. This consistency is important because it suggests that the results of this work will be applicable across a broad spectrum of physiology courses in different institutions.

Second, it was equally noteworthy that our respondents described a core principle that had not appeared on the lists generated at the CAB I meeting. "Interdependence" was a core principle mentioned by many respondents. Respondents referred to two similar but overlapping ideas: *1*) "vertical interdependence" or understating that any physiological function requires understanding processes occurring at many different levels of organization and *2*) "horizontal interdependence," meaning that the organ systems that are described in separate chapters in our textbooks must work together to sustain the life of the organism. We argue that both aspects of this core principle reflect an important agenda of most physiology teachers, namely, that students learn to think deeply and broadly "outside the box" of the individual chapters of their textbooks.

Third, it is also interesting that the core principle "information"articulated by the CAB I participants was expressed by our respondents as two different core principles: "cell-cell communications" and "genes to proteins." Here, too, we argue that this reflects a pragmatic teaching issue related to the sequence of topics that are taught in a physiology course (and there is always a sequence of some kind); textbooks cover the information involved in the transmission of genetic information and the development of cells in one chapter or section and deal with information processing in the nervous system or endocrine system in different chapters or sections.

Fourth, it is clear from an examination of the list of core concepts (Table 4) that many of the concepts overlap with other concepts in important ways. For example, the concept of homeostasis clearly overlaps with the concept of cell-cell communications, since the mechanisms by which homeostasis are produced are dependent on the processing of neural and/or endocrine information.

Finally, it is important to recognize that our attempt to identify core principles and to unpack them into their component parts is a pragmatic one intended to permit us to develop an instrument for conceptual assessment for physiology, i.e., a physiology concept inventory, to join with a growing group of biology concept inventories (3).

Working with a team of other physiology faculty members, we are beginning the process of writing questions for flow down gradients that address some of the component ideas from the unpacking process. Our goal is to unpack the next three core principles ("homeostasis," "cell-cell communication," and "cell membranes") and to assemble a concept inventory for four of the top five core principles in physiology in the next 2 yr.

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DISCLOSURES

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