THE "BIG IDEAS" OF PHYSIOLOGY
PART 2: HOW DO WE KNOW IF THEY UNDERSTAND THEM?

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ABSTRACT

If we expect students to understand the BIG IDEAS of ***physiology*** it is essential that we be able to assess whether they have achieved the level of understanding expected. We describe a process for generating an assessment instrument that can be used with students at all post-secondary levels. This process starts with asking open-ended questions to elicit samples of student thinking about the physiological issues raised. Distracters for multiple choice items are then generated from these free responses. This assessment instrument (the Physiology Big Idea Inventory) can be used to ask whether individual students have achieved conceptual mastery of physiology, whether a physiology course is successful in helping students to learn physiology, or whether some experimental educational treatment works better than some other treatment to improve student learning.

I. INTRODUCTION

In the previous paper (Michael, Modell, McFarland, and Cliff, 2007) we defined nine BIG IDEAS and their component ideas that underpin physiology. One goal for any physiology course should be student understanding of these BIG IDEAS.

How do we assess whether students do, in fact, understand the BIG IDEAS? What is needed is an assessment instrument that specifically targets the student's ability to use an understanding of a BIG IDEA to think about a physiological phenomenon, at least in part, independently of their knowledge of the facts about that phenomenon.

Such a physiology assessment instrument could serve the same functions for the physiology education community that the Force Concept Inventory (Hestenes, Wells, and Swackhamer, 1992) serves for the physics education community. The FCI is thought to test students' understanding of the concepts of Newton's law of motion independently of the students' ability to solve quantitative problems about motion. The FCI has been used to assess individual student understanding of the concepts of physics, the success of courses in helping students learn these concepts, and as a tool for physics education research (see Hake, 1998).

Following development of the FCI and its successful use, a number of other similar inventories have been written in physics (see Maloney, O'Kuma, Hieggelke, Van Heuvelen, 2001), in engineering (see Evans et al., 2003), in chemistry (see Pavelich et al., 2004), and in geoscience (Libarkin and Anderson, 2006).

In this paper we describe a process for developing a Physiology Big Idea Inventory and suggest several approaches to writing questions with the goal of producing a single assessment instrument appropriate for testing all post-secondary students of physiology. Such an assessment tool would contribute to efforts to reform physiology education at all levels.

II. BIG IDEAS OF PHYSIOLOGY

Table 1, taken from our previous paper (Michael, Modell, McFarland, and Cliff, 2007), summarizes the nine BIG IDEAS that students should understand. A more detailed description of them, and the component ideas into which they can be unpacked, can be found in that paper.

It is important to recognize that testing the students' understanding of these BIG IDEAS is difficult to do directly. That is, it is difficult to pose questions about the BIG IDEAS themselves that do not simply elicit the recall of memorized definitions acquired from the lectures or textbooks. However, as we will show, it is possible to write questions dealing with the component ideas that are unpacked from the BIG IDEAS.

TABLE 1
Big Ideas In physiology
(from Michael et al., 2007)

I.	Living organisms are ***causal mechanisms*** whose functions are to be understood by applications of the laws of physics and chemistry.
II.	***The cell*** is the basic unit of life.
III.	Life requires ***information flow*** within and between cells and between the environment and the organism.
IV.	Living organisms must obtain matter and energy from the external world. This ***matter and energy must be transformed and transferred*** in varied ways to build the organism and to perform work.
V.	***Homeostasis*** (and "stability" in a more general sense) maintains the internal environment in a more or less constant state compatible with life.
VI.	Understanding the behavior of the organism requires understanding the relationship between ***structure and function*** (at each and every level of organization).
VII.	Living organisms carry out functions at many different ***levels of organization*** simultaneously.
IIX.	All life exists within an ***ecosystem*** made up of the physicochemical and biological worlds.
IX.	***Evolution*** provides a scientific explanation for the history of life on Earth and the mechanisms by which changes to life have occurred.

III. DEVELOPING AN ASSESSMENT INSTRUMENT FOR PHYSIOLOGY

In thinking about creating a physiology inventory, it is useful to begin by considering some of the features of the Force Concept Inventory (Halloun and Hestenes, 1985; Hestenes, Wells, and Swackhamer, 1992). The FCI is a set of multiple choice questions each of which describes a scenario, poses a question about that scenario, and requires students to apply their understanding of the underlying concepts to select an answer. Such questions are clearly different in style and content from typical physics course exam questions which require some analysis of the scenario described, the identification of relevant equations, manipulation of the equations, and the calculation of a numerical value. The questions making up the FCI are unquestionably testing something different than what is tested by the usual course exam questions.

One significant feature of the FCI is that the distracters, the wrong answers, were written to reflect common student misconceptions (Halloun and Hestenes, 1985). Thus, performance on the FCI assesses both student understanding of the concepts (correct answers) and the presence of misconceptions (wrong answers).

Another important feature of the FCI is that the questions that make it up are appropriate for physics students at any post-secondary educational level. This is, in part, the consequence of physics being a discipline with an essentially universally agreed upon curriculum. It is also a consequence of the focus of the FCI being on qualitative prediction based on an understanding of Newton's Laws, not the analytic or numerical solution to problems.

Physiology is quite different from physics in several regards. For example, in physiology it is not obvious what would distinguish typical exam questions from conceptual questions testing a student's understanding of the BIG IDEAS of physiology. The distinction between testing quantitative/analytical abilities and conceptual understanding is not a prominent feature in physiology.

Equally important, although there is a fairly standard curriculum for physiology courses at the community college level (driven in part by pre-nursing course requirements), other introductory level physiology courses can differ significantly in their content. It is thus an open question whether we can write a set of assessment items that can be used at all post-secondary academic levels.

Thus if the goal is a universally applicable concept inventory the questions must be relatively content independent, or at least deal with content likely to be found in all courses, and the items must be written in simple language.

It seems reasonable to assert that physiology conceptual questions ought to require only an understanding of the BIG IDEAS (and their unpacked component ideas) independently of their knowledge of the details of a physiological system. If we want to know if a student understands the BIG IDEA of homeostasis we do not want the students' ability to correctly answer the question to be determined by his/her remembering the difference between the carotid baroreceptor and the aortic baroreceptor, or their remembering that the central chemorecpetors make a greater contribution to respiratory drive than do the peripheral chemoreceptors. Of course, this does not mean that the instructor can not also expect that students will understand these differences.

Similarly, we do not want the students' ability to answer these questions to be dependent on their having mastered the often esoteric terminology, jargon, and acronyms that abound in physiology textbooks, although it is appropriate to expect some facility with the fundamental "language" of physiology.

These requirements pose significant challenges to writing assessment items. To make questions "course content independent" we can write questions based on topics that are likely to be present in a majority of course. However, the resulting question bank will most likely contain questions that are not appropriate for some courses. Another approach is to write questions which contain all the "facts" that are needed to answer the question ***given an understanding of the BIG IDEAS involved***.

Such questions could be base on:

(1) common, everyday situations such as exercise, exposure to high altitude, development of a fever (see Michael, 1998);
(2) “imaginary” animals with specifically defined characteristics (see Question 3 below); and
(3) non-mammalian species with which most students will be unfamiliar.

With each type of question the student must apply his or her understanding of the BIG IDEAS of physiology to selecting an answer.

If it is not possible to develop one inventory that is universally applicable, then at the least, we want to develop a set of resources that will make it possible to develop assessment instruments tailored to particular educational levels.

The procedures to be followed in developing a reliable and valid conceptual inventory are well known and have been described for a number of different disciplines: physics, geoscience (Libarkin and Anderson, 2007), biology (Garvin-Doxas and Klymkowsky, 2007). Physiology misconception inventories have been developed in a similar way (Michael et al., 1999; Michael et al., 2002). Basically the steps to be followed consist of:

- Writing open-end questions about BIG IDEAS to be administered to a large, heterogenous sample of students.
- Use student answers to these questions to generate distracters for multiple choice questions (MCQ’s).
- Have the MCQ’s reviewed by content experts and experienced physiology teachers.
- Pilot the vetted MCQ’s with large, diverse student populations.
- Revise the questions as needed and pilot test them again.
- Conduct focused interviews with a small sample of students to validate that the distracters used reflect student thinking.
- Revise the MCQ’s as needed.
- Use the assessment items with large numbers of students and collect and achive results.

IV. EXAMPLES OF OPEN-ENDED QUESTIONS ABOUT THE BIG IDEAS OF PHYSIOLOGY

What follows are some very preliminary attempts to generate open-ended questions to be used as described above. Such questions must encourage students to respond in a very open fashion, but must also be sufficiently focused so that students stay, more or less, on task. These are intended to be answered by no more than a short paragraph.

Question 1

Muscle cells and nerve cells perform different functions in the body, yet both require the availability of oxygen in order to maintain their normal functions. Explain.

This question tests the students' understanding of the need for energy to power all the functions of all cells.

BIG IDEA: V(5)

Question 2

Muscle and nerve cells clearly have different functions in the body although they have exactly the same DNA in their nucleus. How do different functions arise in cells with the same DNA?

Although the genes are the same, different sets of genes are expressed (ie., some are NOT expressed) leading to the development of different structures and different functions.

BIG IDEA: IV(1)

Question 3

Investigators observe that in spite of changes in activity and in the external environment, Tribbles exhibit a nearly constant concentration of X in their blood. What does this tell you about Tribbles' physiological mechanisms and substance X?

It can be concluded that the concentration of X is measured by some system in the body, and that alterations in body function can bring about changes in the concentration of X .

BIG IDEAS: III(6 & 7)

Question 4

How do the structural characteristics of the lungs supports their function in gas exchange between the atmosphere and the blood? What structural properties would you predict are present in the lungs to enable this function?

To maximize exchange by diffusion a big surface area and short distance for diffusion are needed.

BIG IDEA: VI(2)

Question 5

The loss of fluid (filtration) from glomerular capillary (in the kidneys) is much greater than in skeletal muscle capillaries. How do the two types of capillaries differ from each other? Explain.

There is a greater area of pores in glomerular capillaries than in skeletal muscle capillaries.

BIG IDEA: VI(2)

Question 6

Very small changes in the concentration of a hormone H in the blood can result in a very large change in the output X from some tissue. Explain the mechanism that accounts for this.

Hormones carry information (only a very small concentration is required) which alters cell function.

BIG IDEA: IV(3)

Question 7

Respiration increases (amount of air moved per minute) when an individual exercises. What causes this to happen?

Mechanisms are activated to make available increased oxygen to exercising muscle. The response does not occur because the muscles “need” more oxygen.

BIG IDEA: I(2)

Question 8

Muscle contain enough high energy compounds to produce ATP to power muscle contraction for only a very short time. Explain how a marathoner is able to run for 2+ hours.

Other cells make glucose which is then supplied to the exercising muscle cell.

BIG IDEA: II(5)

Question 9

Sucrose is a sugar that can not cross the walls of the capillaries. If sucrose is introduced into the circulation water leaves the tissues and enters the circulation. Explain.

An osmotic pressure gradient is presents and results in movement of water down its own concentration gradient.

BIG IDEA: V(2)

Question 10

The XYZ cell of a newly discovered species is found to have a sodium concentration inside the cell of 200 mM/L and a sodium concentration outside the cell of 20 mM/L. What can you conclude about the membrane of the XYZ cell?

The cell membrane is either impermeable to sodium or there is a “pump” in the membrane that actively maintains the concentration gradient for sodium.

BIG IDEA: II(1 & 2)

These questions can be answered by students at essentially any academic level. From written answers we will extract, using student language, distracters to be used in multiple choice questions. These will then be piloted by administration to a large, heterogeneous student population.

V. WHAT DO WE DO NEXT?

We are developing a bank of open-ended questions that test all of the BIG IDEAS through an assessment of student understanding of their component ideas. These questions will be circulated to physiology educators (members of the American Physiological Society and the Human Anatomy and Physiology Society) for comments and corrections. Answers to these questions from the largest and most diverse group of students will be collected using a web-based system. With these responses we will begin the process of constructing a multiple choice assessment instrument following the steps outlined above.

VI. CONCLUSION

Our goal is the development of an assessment instrument appropriate for use in all physiology courses to be used to determine whether students understand (can apply) the BIG IDEAS of physiology. This will necessitate developing questions that are written in non-technical language, and require minimal detailed content knowledge to be answered. Questions testing each of the BIG IDEAS and their component ideas (Michael, Modell, McFarland, and Cliff, 2007) will be written, allowing instructors to choose which questions are most appropriate for use in their course. Even if it proves impossible to produce questions that are useable at all educational levels, we believe that we will have produced a resource bank with we can tailor assessment instruments for different courses.

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