Adv Physiol Educ 31: 389–391, 2007;
doi:10.1152/advan.00047.2007.

Conceptual Assessment in the Biological Sciences: a National Science Foundation-sponsored workshop

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Submitted 2 July 2007; accepted in final form 5 July 2007

Michael J. Conceptual Assessment in the Biological Sciences: a National Science Foundation-sponsored workshop. *Adv Physiol Educ* 31: 389–391, 2007; doi:10.1152/advan.00047.2007.—Twenty-one biology teachers from a variety of disciplines (genetics, ecology, physiology, biochemistry, etc.) met at the University of Colorado to begin discussions about approaches to assessing students' conceptual understanding of biology. We considered what is meant by a "concept" in biology, what the important biological concepts might be, and how to go about developing assessment items about these concepts. We also began the task of creating a community of biologists interested in facilitating meaningful learning in biology. Input from the physiology education community is essential in the process of developing conceptual assessments for physiology.

biology concepts; physiology concepts

PHYSICS TEACHERS have long known that students capable of producing correct solutions to complex quantitative problems nevertheless seem to have a poor understanding of the *concepts* underlying the equations they are using. The development of the Force Concept Inventory (FCI) in 1992 by Hestenes et al. (9) made available to physics teachers an assessment tool with which to unequivocally demonstrate this observation.

The FCI is made up of multiple-choice questions that pose relatively simple situations and ask students to make qualitative (not quantitative) predictions about what will occur in these situations. The distracters (incorrect answers) are derived from free responses (written) from students or from interviews; they represent prevalent misconceptions about the laws of motion (Refs. 7 and 8; see also Ref. 9).

However, the FCI has done much more than simply confirm the suspicions of classroom physics teachers. Using performance on the FCI as a measure of learning outcomes, Hake (6) was able to show quite convincingly that when students learn physics in active learning environments, their level of understanding is greater than that achieved by students learning the same physics in more traditional learning environments. On a smaller scale, but addressing an equally important issue, Mazur and colleagues (11) were able to demonstrate that the "gender gap" in physics classrooms can be closed if the learning environment is one that emphasizes active learning.

The utility of FCI has prompted the development of a number of other concept inventories in other areas of physics. For example, Maloney et al. (12) wrote a Conceptual Survey of Electricity and Magnetism (CSEM) that is being used in the physics community in the same way that they use the FCI.

The situation in biology, and in physiology specifically, is much the same as it is in physics. Physiology teachers have all interacted with students whose answers to an exam question (most often in multiple-choice format) are correct but who are unable to correctly explain why the answer is what it is. Even worse, students often reason quite incorrectly in arriving at a nevertheless correct answer. They got the right answer, but they don't seem to understand the physiology! However, in the biological sciences, we do not yet have an equivalent of the FCI to measure understanding of the important concepts we expect our students to master (10). There are a number of reasons why this is the case, but recently several individual biological disciplines have begun to develop concept inventories (see, for example, Refs. 1 and 3). But, the lack of such validated and reliable assessment tools has certainly impeded research about the learning of biology and, specifically, physiology.

The Conceptual Assessment in Biology Workshop

As one way to address the need for such a tool, the National Science Foundation (Course, Curriculum, and Laboratory Improvement program of the Division of Undergraduate Education) sponsored a workshop on "Conceptual Assessment in the Biological Sciences." The meeting was held in Boulder, CO, on March 2–4, 2007, and it was organizing by Dr. Michael Klymkowsky of the Department of Molecular, Cellular, and Developmental Biology of the University of Colorado.

This workshop brought together a group of 21 biology teachers, educators, and educational researchers with a common interest in student learning with understanding (not just memorizing) in biology. Fourteen different educational institutions were represented.

Prior to the meeting in Boulder, participants were asked to submit short papers summarizing the work that they and their colleagues had done in the area of conceptual learning and/or student misconceptions. These papers can be accessed online at http://bioliteracy.net/CABS%202007.html.

At the meeting, three issues were discussed in some depth. The first issue was what do we mean by a "concept" and what are the concepts that underlie biology. It was acknowledged that it is difficult to define the term concept and that the term may mean different things in different disciplines. The concepts tested by the FCI seem quite different in nature than the concepts that one seems to find in biology.

There was widespread agreement that the term "big idea" may better capture what it is we are seeking to identify. "Big ideas" are defined by Duschl et al. (2) as follows:

> 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.

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Such "big ideas" provide us with tools with which to think about, to understand, natural phenomena. It is the "big ideas" of biology that we want students to understand and remember.

This led to the second issue, namely, what *are* the "big ideas" of biology? No consensus was reached (or even sought) on a definitive list of "big ideas" in biology. However, there was general agreement that the "big ideas" described in Table 1 (the wording is mine) seem to be candidates for inclusion on our final list.

Every biologist of any sort will recognize that *evolution* is the central "big idea" of all of biology, and every physiologist will acknowledge the centrality of *homeostasis* as the "big idea" underlying physiology.

It is also clear that understanding the "big idea" of *homeostasis* means that the students must understand the ideas that collectively make up the "big idea" of *homeostasis*. The "unpacking" of *homeostasis* into its constituent pieces can be seen in Table 2. Each of the other "big ideas" must be unpacked in a similar way. It is likely that the unpacking done from the perspective of physiology looks different than the unpacking done from the perspective of plant biology or any other biological discipline.

Once we have identified the "big ideas" that we want our students to understand, we need to develop assessment instruments that will enable us to determine whether they have achieved the desired level of understanding. The process for generating such items is well understood and was used to develop the FCI (9) and, more recently, the Biology Concept Inventory at the University of Colorado (5). You start by writing open-ended, free-response questions and use the students' answers to determine what misconceptions are present. You can then use the students' words to generate the distracters for multiple-choice questions. The PERC group has used a similar process in generating their misconceptions inventories (13, 14).

Once an instrument is generated, its reliability and validity must be determined by administering it to large heterogeneous populations of students and analyzing the results. The assessment database being assembled by Ebert-May and colleaguesat Michigan State University (3) will be a big help in this process.

Where Are We Going Next?

We are currently planning a second Conceptual Assessment in Biology meeting to take place at the beginning of 2008. The agenda for this meeting will be as follows: *1*) reach a consensus about the "big ideas" in biology, *2*) continue the discussion on writing valid and reliable conceptual assessments that will test students' understanding of these "big ideas", *3*) begin a discussion about how to use conceptual assessment in biology to reform biology teaching, and *4*) document our thinking and our discussions for wider dissemination.

Table 1. *A preliminary list of the "big ideas" of biology*

"Big Ideas" In Biology
1. Living organisms are *causal mechanisms* whose functions are to be understood by applications of the laws of physics and chemistry.
2. *The cell* is the basic unit of life.
3. Life requires *information flow* within and between cells and between the environment and the organism.
4. 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.
5. *Homeostasis* (and "stability" in a more general sense) maintains the internal environment in a more or less constant state compatible with life.
6. Understanding the behavior of the organism requires understanding the relationship between *structure and function* (at each and every level of organization).
7. *Evolution* provides a scientific explanation for the history of life on Earth and the mechanisms by which changes to life have occurred.
8. All life exists with an *ecosystem* composed of physicochemical and biological worlds.

Table 2. *The big idea of homeostasis unpacked*

Homeostasis Unpacked
1. The organism attempts to maintain a more or less constant internal environment that is different than the external environment.
2. Stability of the internal environment occurs via information flow in the form of negative feedback.
3. Some limited set of internal system parameters is regulated (held more or less constant) by the manipulation of other parameters whose values are controlled.
4. The "desired" value of a regulated parameter behaves like a "set point."
5. The value of the set point can change as the situation of the organism changes.
6. The actual value of a regulated variable must be measured by the body (a parameter can only be regulated if it can be measured).
7. The determinants of a regulated variable must be controlled by the body by altering matter/energy transformations.

How Can the Physiology Teaching Community Help?

A working document titled "Big ideas in physiology," written by me, Harold Modell, Jenny McFarland, and William Cliff has been posted at http://bioliteracy.net. It contains an expanded discussion of each of the seven "big ideas" found in Table 1 and the unpacking of the "big ideas" in addition to the one for *homeostasis* shown in Table 2. What we need is your input on the issues that we have raised: What are the "big ideas" of physiology? How can those "big ideas" be unpacked in the most useful way? How should we write questions that will test students' understanding of the "big ideas?" Your comments and corrections are vitally important if the ultimate goal of improving physiology teaching and learning is to be realized.

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