From Misconceptions to Concepts

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Inventorying Physiology Misconceptions

Since the early '90's, I and my colleagues in PERC have been attempting to identify the misconceptions that impede students' learning of physiology. In a parallel effort we have attempted to develop learning strategies that will help students to repair their faulty mental models (misconceptions).

This work began with a study I did to determine whether undergraduates studying physiology were able to predict the responses of physiological systems to disturbances that all had personally experienced. Simple scenarios were described ("a game of tennis") and respondents were asked to predict the changes (increase, decrease, no change) to identified system variables that would occur. While the students surveyed clearly understood that exercise causes an increase in heart rate and an increase in the strength of contraction of the heart, at least half of them exhibited a serious misconception about the responses of the respiratory system to the same disturbance. These students had the misconception that while breathing frequency increases with exercise, the amount of air moved with each breath either decreases or stays the same (Michael, 1998).

This finding suggested several questions. What was the source of this misconception? Was this misconception a common one across students studying physiology at the post-secondary level (the target audience for all of our work)? Were there other misconceptions about respiratory physiology that would affect their learning?

To provide answers to these questions we launched a research project with support from NSF. Members of PERC collectively suggested respiratory phenomena that their students had difficulty mastering. From this list we generated questions describing simple scenarios and asked the respondents to make predictions (usually increase, decrease, no change) about the responses of the system. Adopting the approach described by Treagust (1989), after each question the students were asked to briefly explain (in their own words) the reasoning they had used to make their prediction. The students' written responses were then used to generate explanations for each prediction that could be selected by respondents. Thus, the survey or inventory we developed was a multiple choice instrument, making it feasible to survey large numbers of students.

The results of our first large scale survey (N=700) were of great interest (Michael et al., 1999). There are many misconceptions about the function of the respiratory system, and their prevalence is surprisingly uniform across student populations ranging from those enrolled in community college Anatomy & Physiology courses to students in advanced physiology courses in research universities and medical schools.

PERC then applied the same protocol to generate an inventory for diagnosing the presence of cardiovascular misconceptions. The results again demonstrated a great many misconceptions at all educational levels (Michael et al., 2002). We also sought to determine whether some of these misconceptions were a product of students' lack of understanding of a small number of common physical mechanisms seen in physiological systems ("pressure/flow/resistance," "reservoirs," "elastic structures" – see Modell, 2000). The results suggested that indeed many students exhibiting certain misconceptions also exhibited an inability to make predictions about these common phenomena.

We have more recently begun to look at misconceptions about renal physiology. From a preliminary examination of the responses it is clear that if certain simple ideas are poorly understood (for example, the "concept" of concentration), it is more likely that certain misconceptions will be present.

Having demonstrated the presence of many misconceptions about physiological functions, members have PERC have also asked whether there are educational "treatments" that will maximize the probability of helping a student to correct the faulty mental model that underlies the misconception. We have had some success in demonstrating that simple changes to a standard physiology student laboratory protocol results in a significantly greater chance of helping student repair a misconception (Modell et al., 2000; Modell et al., 2004).

Our work cataloging physiology misconceptions in diverse undergraduate populations is continuing and we intend to write misconception surveys for other major topics in physiology (cell, muscle, endocrine). We are also continuing our studies of teaching approaches that will help bring about conceptual change (correct faulty mental models).

Inventorying Conceptual Understanding in Biology

More recently we have turned our attention to what I would call the "inverse problem," namely, identifying the concepts that we want our students to take away from their study of physiology. This was prompted in part by the feeling that this issue was an important one in its own right, and that it would also contribute to our uncovering student misconceptions. My discovery of Mike Klymkowsky's biology concepts website was certainly another stimulus to begin thinking about this issue.

However, defining what is meant by a "concept" (in any domain) has proven to be a daunting task. I have asked a number of physicists who work with the Force Concept Inventory what they mean by a "concept," and they were unable to offer a definition. It may, in fact, be more useful to think about "big ideas" in biology.

"Big ideas" have been defined by Duschl, Schweingruber and Shouse (in press) 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."

The key notion, I think, is that "big ideas" have great utility for learning the discipline now and for continued learning in the future.

The task facing the participants at this meeting is to begin the process of generating inventories of biology "concepts" or "big ideas" with which to determine whether students are actually learning those ideas we believe to be important. It is clear that in some sense the ultimate goal is to do for biology education what the Force Concept Inventory (and others like it) has done for physics education. (I recognize that physics and biology are distinctly different disciplines, and that physics courses and biology courses have very different constraints determining what is taught and how.)

It seems to me that there are two tasks to be undertaken.

(1) We need to determine what it is we want our students to understand (not simply know). Whether we call the things we want them to understand "concepts" or "big ideas" (or "principles"), we must begin considering operational approaches to compiling lists of the things we will then want to be able to assess.

(2) We need to develop assessment instruments with which to test student understanding, and, from the outset, we must deal with the issue of determining the validity and reliability of the assessment we produce.

Given the breath of the biology domain and the breath of the student populations we are interested in we will need to develop different concept lists and different assessment instruments for different domains and different student populations. It is also important to remember that our global goal is to improve the learning that occurs in biology courses, and that our concept lists and concept inventories will have to be applicable and useful in real classrooms.

A Note on "Big Ideas" in Biology

I think there are perhaps five "big ideas" that are applicable in all domains of biology. They are:

The "Big Ideas" of Biology

- Evolution
- Homeostasis (in the organism) or equilibrium (cellular processes, populations or ecosystems)
- Matter and energy transformations (at all levels of organization from the cell to the ecosystem)
- Information flow (at all levels of organization)
- Ecosystems

Each of these "big ideas" contains (in a nested fashion) other "big ideas," as well as many, perhaps "not so big" ideas. For example, homeostasis unpacks into such ideas as:

Homeostasis Unpacked

The internal environment (in which all cells live)
Information flow
Negative feedback
Energy transformations.

We if continue to unpack "homeostasis" still further we eventually get to the physiology concepts posted on the biology concepts website. Each of these concepts can then be turned into a learning objective for a particular course.

It is not trivial to write exam questions that test students' understanding of course learning objectives, but it is certainly do-able. It is also possible to write inventory items that can test conceptual understanding of the ideas that unpack from "homeostasis." It is not clear how to write items that will assess understanding of the "big ideas" sitting on the top of the hierarchy. This, will clearly be one of the challenges for our future work.

Conclusions

The work of uncovering student misconceptions is underway in most of the sub-disciplines of biology. The results have been deeper insights into student thinking about biological phenomena, and this has, in turn, started to inform what and how we teach in the classroom.

It is now time for biologists to turn to the more daunting task of making decisions about concepts or "big ideas" students ought to take away from their study of any of the biological sciences. Since there is presently more known than we can expect students to learn, we need to start making choices about what should be learned. The answer, of course, is that it is the "big ideas" that every student should understand.

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