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The second Conceptual Assessment in the Biological Sciences workshop

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Michael J, McFarland J, Wright A. The second Conceptual Assessment in the Biological Sciences workshop. *Adv Physiol Educ* 32: 248–251, 2008; doi:10.1152/advan.90122.2008.—A second National Science Foundation-sponsored workshop on Conceptual Assessment in Biology was held in January 2008. Reports prepared for the workshop revealed that research groups working in a variety of biological sciences are continuing to develop conceptual assessment instruments for use in the classroom. Discussions at this meeting largely focused on two issues: *1*) the utility of the backwards design approach of Wiggins and McTighe (11), in which identification of learning outcomes (determining what to assess) lies at the beginning of course design; and *2*) the utility of defining expected learning outcomes as the building of runable mental models (and designing conceptual assessments that would test the correctness of these mental models). A third meeting is being planned that will focus on the processes involved in writing and validating conceptual assessment instruments.

biology concepts; mental models

THE FIRST National Science Foundation (NSF)-sponsored Conceptual Assessment in the Biological Sciences (CAB) workshop (CAB I) was held on March 2–4, 2007, in Boulder, CO. Three reports of this workshop have been published (3, 5, 9). The workshop discussion and the contributed papers should be of interest to physiology faculty working on the assessment of student learning, program assessment, or research about the efficacy of specific teaching and learning practices (5).

The focus of this meeting, and that of the second, subsequent NSF-sponsored CAB workshop (CAB II) (see below), was the creation of one or more conceptual assessment instruments or inventories that can be used to determine whether students understand the concepts or principles of biology. A "conceptual assessment" instrument must be distinguished from conventional course exams, which typically test students' retention of the "facts" of biology and, to some extent, on their ability to use these facts to solve problems. For example, a "conceptual assessment" in physiology might ask students to demonstrate their understanding of negative feedback in some homeostatic system, in contrast to a course exam, which might ask students to name the components that make up that system. (In physics, the contrast between a concept inventory and a course exam is often quite dramatic, with concept inventories asking questions about qualitative changes in variables while course exam questions typically ask for calculations of quantitative changes.)

Three issues took center stage at this first workshop. First, participants, educators, and educational researchers in a variety of biology disciplines were informed what others in this field were doing. The collection of preworkshop papers contributed by the participants can be accessed at the Bioliteracy website (http://bioliteracy.net) under the heading "CABS I and II." Second, although no consensus was achieved, there was general agreement that the term "big idea" best captured what the group wanted to assess. "Big ideas" are unifying concepts that apply in all areas of biology and can be considered as the foundation for everything the student learns in biology. A preliminary list of "big ideas" in biology was generated (see Ref. 5). Finally, the group discussed of how to generate a concept inventory with which students' conceptual understanding could be assessed.

This enterprise can contribute significantly to our evolving ideas about physiology teaching because of its focus on defining what students should know (the "big ideas") and then designing an assessment instrument to determine whether our students do, in fact, know them.

The Second Conceptual Assessment Workshop

CAB II was held on January 3–6, 2008, in Asilomar, CA. Twenty-seven biology educators attended the workshop, with many attendees from the first CAB workshop returning and several new people joining the group. The diversity of biology disciplines was somewhat wider than at the first CAB workshop.

As was the case at the first workshop, the first item on the agenda was bringing the group up to date on the continued work that had occurred since the first meeting. Preconference papers had been written and circulated; they can be found at the Bioliteracy website (http://bioliteracy.net) under "CAB I and II" papers. Table 1 shows the titles and authors of the papers found at that website.

Most of these papers focused on the development of conceptual assessment instruments for use in the biology classroom and as a tool in conducting educational research. These papers reflect the diversity of biological science disciplines and topics for which concept inventories are being developed (introductory courses, genetics, microbiology, and natural selection) and the different stages in the development of these instruments. Some of the most useful papers discuss guidelines for test item development and processes for the assessment/validation of these assessment instruments (including student interviews as well as quantitative data collection). Thus, the goal continues to be the development of pedagogically useful conceptual assessment tools for the biological sciences.

One issue that arose early in our discussions was the use of the term "big idea." While there was general agreement about what the term referred to, there was no agreement that this was the best label for us to use. The concern expressed was that this term carries "too much baggage" and might be misunderstood or misinterpreted by other members of the biology education com-

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Table 1. *Papers submitted to the CAB II workshop found at the Bioliteracy website*

Diagnostic question clusters to improve student reasoning and understanding in general biology courses: faculty development component (p. 1).
Charlene D'Avanzo,* Deb Morris, Andy Anderson, Alan Griffith, Kathy Williams,* and Nancy Stamp
Hampshire College, Amherst, Massachusetts

Genetics concepts inventory (GenCI) development (p. 10)
Susan Elrod*
California Polytechnic State University, San Luis Obispo, California

The biology concept inventory (BCI) project: status and issues (p. 22)
Kathy Garvin-Doxas and Michael W. Klymkowsky
University of Colorado, Boulder, Colorado

Connecting K–12 science reform to higher education STEM (p. 31)
Paul J. Kuerbis*
Colorado College, Colorado Springs, Colorado

Studying C-tools: automated grading for online concept maps (p. 32)
Douglas B. Luckie,* Scott H. Harrison, Joshua L. Wallace, and Diane Ebert-May*
Michigan State University, East Lansing, Michigan

The "big ideas" of physiology. Part 1: what should students understand? (p. 39)
Joel Michael,* Harold Modell, Jenny McFarland,* and William Cliff
Rush Medical College, Chicago, Illinois

The "big ideas" of physiology. Part 2: how do we know if they understand them? (p. 53)
Joel Michael,* Harold Modell, Jenny McFarland,* and William Cliff
Rush Medical College, Chicago, Illinois

Frameworks for reasoning and assessment in Mendelian genetics (p. 63)
Joyce Parker,* Charles Anderson, Merle Heidemann,* Mark Urban-Lurain,* John Merrill,* Brett Merritt, Gail Richmond, and Duncan Sibley
Michigan State University, East Lansing, Michigan

Eliciting big ideas in biology (p. 69)
David Niemi and Julia Phelan*
National Center for Research on Evaluation, Standards, and Student Teaching, University of California, Los Angeles, California

An assessment of student comprehension of the "big ideas" in biology in the context of general education courses (p. 86)
Joelle C. Presson,* Kathy McAdams, Pam Lanford, Therese Leslie, Dave Straney, Edgar Moctezuma, and Janet Coffey
University of Maryland, College Park, Maryland

Connecting the "big ideas" in biology with those of other disciplines (p. 93)
Duane W. Sears*
University of California, Santa Barbara, California

A faculty team works to develop a concept inventory that measures understanding of microbiology revelvant to host pathogen interactions (p. 96)
Ann C. Smith, Gili Marbach-Ad,* Volker Briken, Najib El-Sayed, Kenneth Frauwirth,* Brenda Frederickson, Steven Hutcheson, Lian-Yong Gao, Sam Joseph, vincent Lee, Kevin S. McIver, David Mosser, B. Booth Quimby, Patricia Shields, Wenxia Song, Robert T. Yuan, and Daniel C. Stein
University of Maryland, College Park, Maryland

Using diagnositic test items to assess conceptual understanding of basic biology ideas: a plan for programmatic assessment (p. 108)
Kathy S. Williams,* Kathleen Fisher,* Dianne Anderson,* and Mike Smith*
San Diego State University, San Diego, California

Students learn about their own bodies as part of their biological and citizen deduction. How do they learn? What do they learn first? From whom do they learn? (p. 120)
Ann Wright*
Canisius College, Buffalo, New York

Papers submitted to the second Conceptual Assessment in the Biological Sciences (CAB) workshop (CAB II) can be accessed at the Bioliteracy website at http.bioliteracy.net by clicking on the "CAB I and CAB II" heading. These papers are available as a single .pdf file. The starting page number of each paper is shown as well as the institutional affiliation of the first author of the paper. *Authors who participated at the CAB II meeting.

munity. A reading of the preconference papers reveals that there continues to be a number of different terms being used to label the same things, including: "big ideas," "core concepts," "guiding principles," organizing principles, and "enduring understandings."

There was also no sustained attempt to reach consensus on a list of "big ideas" or "core concepts," although throughout the 2.5 days of discussion there were repeated references to "evolution," "information flow," and "matter and energy" (see Ref. 5 for a more complete description of these "big ideas" or principles).

It was agreed that, whatever term we use, to build an effective assessment instrument it is essential to determine what it is students need to know (understand) and be able to do. This led to a discussion of the backwards design paradigm for course or curriculum planning (Refs. 4 and 11; Ref. 6 described a very similar paradigm). The backwards design process involves three steps.

- First, define desired learning and performance outcomes. What will successful students know and be able to do?
- Second, build effective assessment tools that will determine whether these outcomes have been reached. What does successful student learning look like?
- Design learning experiences that will assist students in achieving the desired learning outcomes. What should happen in the classroom and/or laboratory?

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The first two steps lie at the heart of the conceptual assessment agenda: what do we want students to understand and be able to do and how can we effectively assess whether they understand the fundamental concepts? Participants broke up into four small groups with each group attempting to apply the backwards design process to a different biology topic (cell cycle, cell signaling, natural selection, and population dynamics). When the products of this work were shared with the entire group, it was clear that this approach was potentially useful in guiding our thinking about what to assess.

The participants then grappled with the problem of more precisely defining the intended learning goals so that they could be assessed. Wendy Newstetter, a learning scientist, suggested that defining learning goals in terms of "runable mental models" rather than memorized lists of propositions might be helpful. A runable mental model is a mental representation (usually representable as a visual image) of the system under consideration with which one can reason qualitatively and, in some cases, quantitatively (2, 7, 10).

To familiarize the participants with such runable models, the baroreceptor reflex was developed by Joel Michael as an example (Fig. 1) (see Figs. 5-2 and 5-3 in Ref. 1 for more sophisticated models of the same system). "Running" this model makes it possible for the user to correctly predict how the system will respond to perturbations or to explain the mechanism(s) giving rise to observed changes in a perturbed system. For example, one can accurately predict the consequences of a hemorrhage by starting with a decrease in blood volume and then propagating the disturbance (see Fig. 1) to determine the change in mean arterial pressure that results. Knowing how mean arterial pressure changed allows the user to correctly predict the reflex changes that will result. The assessment of a student's mental model and how similar it is to that of the expert can be easily made by posing other perturbations and asking the students to make predictions about the system response (8).

Michael also pointed out that models like this provide a structure for organizing the facts that are accumulated about the topic at hand. For example, each of the boxes in Fig. 1 can be viewed as a folder in which students place everything they know about that particular variable. Relating the facts to one another in this way provides yet another mental representation of this important system.

The next round of small group work then focused on producing a runable model for the four topics previously worked on. The results of this work were shared with the entire group. In general, the different groups found it useful to build runable models that could be used by students to solve problems; the model, then, can be defined as the desired learning outcome.

There was also much discussion by the entire group about student misconceptions or "naïve conceptions" that must be addressed in conceptual assessment to facilitate student learning. There was wide recognition that when students develop their mental models they often apply a few general classes of pervasive misconceptions that interfere with the production of accurate mental models. These include naïve conceptions, misunderstandings, or misapplications regarding cause and effect, randomness, and scale/hierarchy. A set of these recurring misconceptions was addressed in each of the small working groups as the runable models were developed and assessments were designed. It appears that assessing the output of students' runable models offers an approach to assess what students know and what misconceptions they have.

The Next Steps

An official report of the proceedings of the CAB II workshop is being written. The papers prepared by participants have been posted on the Bioliteracy website, and some may be published by the authors in appropriate journals.

The group is also assembling an annotated bibliography of references relevant to the field of conceptual assessment of biology, and this will be made available to the community of biology educators when it is completed.

Finally, a third meeting is being planned for autumn 2008. This meeting will focus on the writing, validating, and analyzing of questions for a conceptual assessment inventory.

We feel that this work on the development of concept inventories in biology is important for physiology. First of all, it provides a guide for defining what students *should* understand; in the face of the information explosion in physiology (visible in the rapidly growing length of even introductory

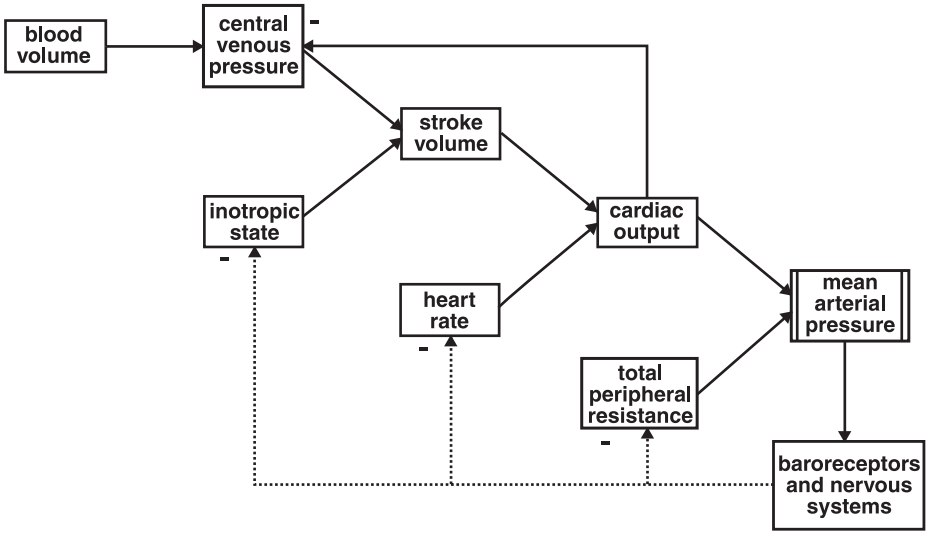

Fig. 1. A runable model of the baroreceptor reflex. The solid lines represent physical interactions, whereas the dotted lines represent neural signals. The minus signs indicate that the changes occurring to inotropic state, heart rate, and total peripheral resistance are opposite in direction to the changes that occur in mean arterial pressure. The minus sign at central venous pressure indicates an inverse relationship with cardiac output.

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textbooks), it provides a way to focus on what is truly important. An assessment instrument will then provide a tool for both formative and summative assessment in the classroom. Finally, such an assessment instrument will provide the community with a tool for education research to assess and improve physiology education.

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