Helping the Learner To Learn: The Role of Uncovering Misconceptions

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Several years ago, we began to explore the prevalence of certain "misconceptions" held by undergraduate students entering physiology courses (Michael, 1998; Michael et al., 1999). Our intent, similar to those of investigators in physics and chemistry education with respect to their disciplines (Pfundt & Duit, 1994), was to gain a better understanding of the conceptual and reasoning difficulties (i.e., "misconceptions") that might impede entering students' ability to construct robust mental models of physiological systems and phenomena. However, the vocabulary used by investigators studying misconceptions seemed inconsistent. This constituted a significant communication problem for us, and, presumably, for other investigators. Many different terms or labels describe apparently similar "things," and the distinctions between the terms are often unclear.

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Historically, a prominent goal of "misconceptions" research was to uncover conceptual difficulties in a particular discipline and to gain insight about the origins of these misconceptions. For example, did these conceptual difficulties arise because perceptions of phenomena occurring in the real world were seemingly not consistent with the scientific explanation of those phenomena? If that was the case, one particular label seemed appropriate. If this was not the case, another label seemed appropriate. For early investigators, "misconception" was too generic a term. Thus, other terms were used to emphasize specific characteristics of the conceptual difficulty. "Naive beliefs" and "preconceptions," for example, were used to refer to ideas that students develop about something *before encountering* that same subject in the classroom. Subsequently, proposals were made to clarify or unify the terminology. "Alternative conception" was proposed (Smith, diSessa & Roschelle, 1993; Wandersee, Mintzes & Novak, 1994) to refer to "experience-based explanations constructed by a learner to make a range of natural phenomena and objects intelligible."

For the novice to the field, the terminology offers more confusion than clarification. For us, these differences in terminology became an impediment to communicating with other investigators in this field. It became clear that educators, classroom teachers, and educational researchers could benefit from an attempt to define a common language for talking about misconceptions or, at least, to agree upon a set of definitions.

The Meeting

To this end, and with the encouragement of the National Science Foundation, we convened a meeting of physicists, chemists, biologists, and science educators who had experience with issues related to "misconceptions" in their own disciplines. The attendees and their disciplines are listed in Table 1.

The intent of this meeting was to draw on the perspectives of the various participants to build a unified vocabulary that could be offered to our community of life science researchers and educators. We also hoped that the results of our conversation would lead to suggestions for ways of thinking about misconceptions that would be particularly useful for life science teachers.

However, a significantly different outcome emerged. The discussion led us to a new view of the significance of misconceptions and the importance of uncovering their presence by teachers in the classroom. Our focus changed from an issue related to vocabulary to one dealing with the value of uncovering conceptual or reasoning difficulties in classroom practice. That is, how can uncovering "misconceptions" in the classroom help instructors whose goal is to help the learner to learn their discipline? We also came to appreciate the extent to which the complexity of the life sciences contribute to student difficulties and the development of misconceptions.

Misconceptions

All teachers have encountered students whose understanding of a concept or principle is not consistent with generally accepted views or interpretations of that concept. We say that such students have "misconceptions" about the concept or principle. Where do these misconceptions (conceptual or reasoning difficulties) originate? What can we learn about our students by uncovering these misconceptions? How can learning more about these misconceptions help us improve classroom practice?

These and related questions have received considerable attention in the science education literature. As a result, a large number of misconceptions have been identified in physics, chemistry, and in biology (Pfundt & Duit, 1994). The messages that this research offers to life scientists interested in misconceptions are:

- The sources from which conceptual and reasoning difficulties arise are varied and can be complex.
- The conceptual and reasoning difficulties can be deep-seated and, thus, difficult to "remedy."
- The instructor cannot correct the problem, the student must do this work.

Table 1.
Attendees at "Misconceptions" Meeting
22-23 June 2001

CHEMISTRY	Mary Nakleh	Purdue University
	Bill Robinson	Purdue University
BIOLOGY	Joel Mintzes	University of North Carolina/Wilmington
	Joel Michael	Rush Medical College
	Mary Pat Wenderoth	University of Washington
	Harold Modell	National Resource for Computers in Life Science Education
PHYSICS	David Hammer	University of Maryland
	Lillian McDermott	University of Washington
	Jim Minstrell	Talaria,Inc.,Seattle,WA
INTERDISCIPLINARY/COGNITIVE SCIENCE	Peter Hewson	University of Wisconsin - Madison
	Jill Marshall	University of Texas - Austin
	Neil Stillings	Hampshire College

Having recognized that learners must correct their own ideas or mental representations, the immediate concerns of the classroom teacher are:

1. to determine if conceptual or reasoning difficulties (misconceptions) are present in their student population,
2. to help students recognize the need for changing their mental representations, and
3. to help them make appropriate changes to their mental constructs.

In this context, it may not be entirely germane to categorize these conceptual and reasoning difficulties according to the schemes established by the early investigators of misconceptions (i.e., naive conceptions, preconceptions, alternative conceptions). They are conceptual or reasoning difficulties that currently exist and that the instructor must help the student remedy.

The relevant question, then, becomes:

What is the utility of uncovering misconceptions in my own classroom practice?

The purpose of this paper is to address this question. As physiologists, we will approach the issue from the perspective of our own discipline. Examples, however, may just as easily be drawn from the full spectrum of biological science, or, for that matter, other areas of science.

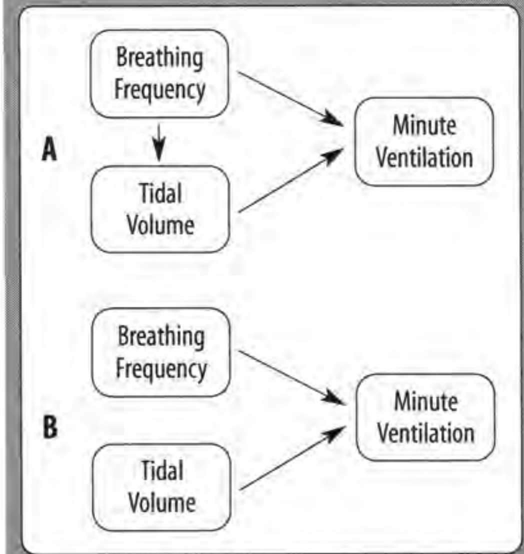
Before proceeding, it is important to clarify some terminology used in this discussion. We routinely use the term "mental model" to refer to the conceptual framework that a student develops in learning about a particular physiological phenomenon. When students learn a new discipline, they must acquire a knowledge base about that discipline. This includes acquiring a store of facts, concepts, principles, etc. The new knowledge must be organized into some mental representation or model that links the newly-acquired pieces of information to one another and to all of the learner's existing knowledge and models. These mental representations may lie on a spectrum from those that are ill-defined or ill-formed to those that are well-defined or well-formed. In any case, these representations are what students use to think about the discipline and the real world. Hence, they may be considered to be mental models of the phenomenon in question. Greca and Moreira (2001) have discussed the notion of a mental model in the learning and teaching of physics. These authors suggest that the term, mental model, can refer to a spectrum of mental representations. They assert that students have built an adequate mental model when the predictions and/or explanations they generate agree with those arising from a scientifically accepted model. In physiology, the models to be built are generally expected to be causal models (represented, for example, by flow charts, block diagrams, or various other pictorial representations) with which students can analyze physiological systems.

It is important to recognize that these mental models often may be flawed. That is, they may not conform to accepted models, they may not have an appropriate level of complexity for the problems the student will be expected to solve, or, as the model has been built, the individual elements of the model (which may be correct) may not have been integrated into existing models in an appropriate way. Students display misconceptions when they apply their mental models to a problem and reach an inappropriate answer. The difficulty may be related to the model they have constructed or the way in which they have applied the model. The misconception, then, is a result of these conceptual or reasoning difficulties. For the learner, the significance of these difficulties is that they interfere with the student's developing an understanding of the discipline.

What is the significance of the presence of a misconception from the perspective of the teacher? The teacher is concerned with helping the learner to learn. Although it may be interesting to learn about the historical development of the student's conceptual or reasoning difficulties, it is of more immediate concern to the classroom teacher to determine how the teacher can help the student modify his or her mental model so that he or she can appropriately analyze biological problems. The teacher's job is to help the student recognize that his or her mental model leads to erroneous conclusions or that the way the model is applied leads to faulty conclusions. In either case, the student must modify his/her model or application of it. To accomplish this task, the instructor must recognize that the origin of difficulties may be varied. In physiology, they may result from misinterpretation of personal experience of physiological phenomena (Michael, 1998), from faulty mental models of fundamental physical and chemical phenomena, from inappropriate integration of accurate mental models of fundamental physics and chemistry phenomena, from informal learning, or from what was learned previously in school. They may have their bases in misunderstandings of language (Veiga, Costa Pereira & Maskill, 1989; Jacobs, 1989), either written or verbal, in errors in textbooks (Storey, 1991), or in misconceptions held by teachers (Mohapatra & Bhattacharyya, 1989).

Figure 1.

Pictorial representations of students' mental models for explaining changes in minute ventilation seen during exercise. **A.** The inappropriate model in which breathing frequency determines tidal volume, and the combination determines minute ventilation. **B.** The appropriate model in which breathing frequency and tidal volume are independent variables that determine minute ventilation.



It is important to recognize that *the teacher cannot correct the student's mental model. Only the student can modify his/her mental model.* Thus, telling the student that his/her mental model is wrong is not sufficient to affect change (Smith, diSessa & Roschelle, 1993; Macbeth, 2000). The student must recognize, by testing his/her mental model, that a difficulty exists and that his/her model or the way it is being applied leads to incorrect or inappropriate conclusions (Macbeth, 2000).

So, what is the utility of recognizing the presence of a misconception? Does uncovering a misconception merely add another problem to the list of problems that students have with the material? No, uncovering a misconception, if used as the first step in a diagnostic process, helps the instructor gain insight into how the student is thinking about a concept or set of concepts, and helps the instructor design a course of action to help the learner modify his/her mental model or its application. Consider the following situations.

Situation 1

When asked, almost all students will correctly predict that during vigorous exercise, heart rate increases, and the strength of contraction of the heart increases. Both of these responses are immediately perceptible to the individual exercising (Michael, 1998). However, when asked about the changes that occur in breathing during exercise (a phenomenon that is seemingly as readily perceived), student responses are likely to be wrong about half of the time (Michael, 1998; Michael et al., 1999). Students correctly predict that the number of breaths per minute (breathing frequency) increases during exercise. However, when asked what will happen to the depth of breathing (tidal volume) during these conditions, about half of the students incorrectly predict that the depth of breathing will stay the same or actually decrease.

What conceptual difficulty does such a pattern of answers suggest? Michael et al. (1999) asked students to explain the predictions that they made, either by free response or by selecting from a set of choices. By far, the most common explanation for predicting a decrease in the depth of breathing was that with an increase in breathing frequency, there isn't enough time to increase the depth of breathing. Therefore, tidal volume must decrease or stay the same (Michael et al., 1999).

Thus, the student model seems to be one in which breathing frequency determines the time available for inspiration which, in turn, determines the tidal volume (see Figure 1A). What is significant about this model is that it will work correctly if the student is asked what effect a change in either parameter **alone** has on the amount of air moved per minute (minute ventilation). It is only when a problem is posed in which **both** parameters change simultaneously that the model fails.

An examination of the mechanism that produces inspiration reveals that the increase in respiratory effort present during exercise causes the pressure gradient causing flow to be increased. Thus, even though the time available for inspiration is shorter, the total flow will be greater. Hence, the more correct model is shown in Figure 1B. This model shows that breathing frequency and tidal volume are independent variables that both contribute to minute ventilation. It is likely that students who incorrectly predict the change in tidal volume that occurs during exercise (or any other condition leading to an increase in minute ventilation) lack an understanding of these mechanisms.

The question that was answered incorrectly, then, can be viewed as being **diagnostic,** and the incorrect answer is a **diagnostic sign,** of the underlying conceptual and/or reasoning difficulty. Further probing (i.e., questioning) can often reveal the nature of the student's problem in greater detail. One can gain insights into whether the source of the error lies with the elements of the student's mental model or with the way in which the elements are linked with respect to the physiological problem that has been posed. Often it is also possible to determine what *the student* must do to recognize the source of the conceptual or reasoning difficulty and address the difficulty.

Situation 2

After reading their physiology text, students often describe the cardiac cycle in the following way. The left atrium contracts forcing blood into the ventricle, then the ventricle contracts, increasing pressure in the ventricle. This, in turn, causes the atrioventricular valve to close and the aortic valve to open. Blood is then ejected from the ventricle. After all of the blood has been ejected, the ventricle relaxes, and the cycle is complete. This description reveals at least two possible diagnostic signs of conceptual or reasoning difficulties (misconceptions). First, that the flow from the atrium to the ventricle occurs only during atrial contraction, and, second, that ejection is complete only when all of the blood in the ventricle has left this chamber.

Flow from the atrium to the ventricle occurs whenever a pressure gradient exists from the atrium to the ventricle. Furthermore, the atrioventricular valve is open whenever the pressure in the atrium exceeds the pressure in the ventricle. In the case of the first conceptual or reasoning difficulty, the instructor can help the student recognize the problem by asking what causes the valve to open, when in the cycle the atrium contracts, and what happens between the time that the valve opens and the atrium contracts. Students recognize the conundrum and modify their mental models of the process to include flow from the time that the valve opens until the time that it closes.

Ventricular contraction begins when calcium ions enter ventricular muscle cells during an action potential. It continues until the cell repolarizes and sufficient calcium ions are transported from the cytosol back into the sarcoplasmic reticulum and extracellular fluid. Thus, the time of contraction depends on ionic events occurring in ventricular muscle cells rather than the amount of volume that has been pumped. Asking students to reconcile ionic and mechanical events requires them to reexamine their mental models of ventricular contraction and to modify them so the links between ionic and mechanical events are included.

These examples illustrate conceptual or reasoning difficulties that have their bases in the students' mental models of the events under consideration. In Situation 3, the problem lies elsewhere. Using an incorrect answer as a diagnostic sign enables the instructor to help students recognize a different kind of problem that impacts their learning of this phenomenon; a problem that can have significant impact on their learning in other content areas.

Situation 3

In this situation, students are asked to locate the arterial systolic blood pressure on a graph of left atrial, left ventricular, and aortic pressures plotted as a function of time. The curves are not labeled. Hence, the student must recognize which line represents aortic pressure and where on that plot arterial pressure during systole is represented. A significant number of students have trouble completing this task. When questioned further, one discovers that the problem is not which curve represents data from which location. Instead, the problem is understanding the task. If the question is restated as, "Locate the point on the graph that represents the pressure measured in the arteries during systole," most students identify the appropriate point on the graph. The problem is not their mental model of the pressure relationships among the various locations in the cardiovascular system. The problem is their inability to parse the phrase, arterial systolic blood pressure. Many students today are not familiar with language constructs that are familiar to their parents and grandparents. As a result, a significant communication problem can arise between instructors of an older generation and students of a younger generation, and between textbook authors and their intended audience. In this situation, viewing the result of the misconception as a diagnostic sign would help the instructor identify a much broader problem; one that could impact any conversation in which multiple adjectives are used in sentence construction. By recognizing this, the instructor could help students identify the problem and encourage them to seek clarification when the sentence structure is not clear.

The Issue of Complexity

Each of our situations illustrates types of problems that can arise in any science classroom. In the first, links between elements of the student's model were inappropriate. In the second, students failed to examine the implications of their models. In the third, misunderstandings resulted from differences in the use of language. In the biological sciences, there is an additional source of potential conceptual and reasoning difficulties. This additional source is the complexity of the systems being studied.

The challenges facing students in the life sciences are often more complex than those facing students learning the physical sciences. This is generally reflected by the types of questions we ask of students and the types of problems that we expect them to solve. For example, in chemistry, students must deal with concepts describing events at the microscopic (atomic) level and at the macroscopic (molecular) level (Herron, 1990; Ben-Zvi & Gai, 1994). In biology, students must have an understanding of basic physics and chemistry concepts, and they must be able to apply these at different levels of organization. Hence, conceptual difficulties with basic physics and chemistry principles can lead directly to conceptual difficulties in biology. However, because biology students must apply these principles at multiple levels of complexity, there is a greater probability that difficulties encountered by biology students may be related to inappropriate application of these principles. In physiology, for example, students must deal with ion movement, molecular mechanisms, and mechanisms at the cellular level, at the tissue level, at the organ level, at the system level, and at the level of the whole organism. In addition, students must be able to shift their focus among these levels of complexity depending on the phenomenon being considered or the problem being solved.

Consider, for example, the task facing a physiology student who is expected to describe how the cardiovascular system responds to a decrease in mean arterial blood pressure, a systemic level variable. The student must understand baroreceptor function (cellular level), nerve and synaptic transmission (molecular level), mechanisms determining cardiac output and total peripheral resistance (systemic level) and, finally, determinants of mean arterial pressure. If the perturbation is longstanding, renal function (organ level) must also be included in the explanation (interaction at the system level). If the student is also expected to make predictions about how changes in blood pressure affect human performance (e.g., exercise), he/she must also be able to apply these mechanisms to the organismic level. Seeking diagnostic signs of conceptual and reasoning difficulties can help the instructor identify the level of complexity at which the difficulty is occurring. Having this information can enable the instructor to help the student address issues related to the complexity of his/her mental model. It can also help the student face challenges that arise when it is necessary to move between or among the various levels of complexity inherent in the problem.

Conclusion

The view that emerges from the ideas we have presented is that students often reveal their conceptual and reasoning difficulties by providing "funny" answers to our questions or by providing erroneous explanations of biological phenomena. These problems cannot be solved by providing students with the correct information. The students, themselves, must correct the problem. The misconceptions represent diagnostic information that helps us determine ways to help students test and refine their mental models. Hence, the practice of uncovering misconceptions as a routine part of classroom practice offers a valuable diagnostic tool. The instructor can use this tool to direct further probing in order to develop a clearer picture of students' mental models and their conceptual and reasoning difficulties. This practice provides a means of helping the *instructor help learners* recognize errors in their mental models. By doing so, *students* are more likely to modify their mental models in ways leading to better understanding of biological phenomena.

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