ONLINE ARTICLE

Instructional Tools
To Probe Biology Students' Prior Understanding

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The starting point and the end goal for any instructional practice is student understanding. Students enter biology classrooms with ideas about the nature of life and of living organisms, and good instruction will take these prior understandings into consideration (Arnaudin & Mintzes, 1985). Modern educational theory, as evidenced in the conceptual change model of learning, encourages science instructors to focus less on fact-based, rote learning mechanisms and more on conceptually-driven instruction (NCR, 1996; Posner et al., 1982). In teaching for conceptual change, the instructor plans instruction by first eliciting students' prior understandings and then incorporating these understandings into the learning structure of the class (Champagne et al., 1980). One challenge to teaching for conceptual change is to find new ways to formatively assess (probe) what students know. In this article, probing strategies will be discussed for assessing students' understanding prior to and during instruction.

Tools for Determining Students' Prior Knowledge

Scientific explanations sometimes require students to think in novel ways. Students' thinking about scientific phenomena often comes from informal experiences. Sometimes the student's thinking is congruent with scientific understanding and sometimes the thinking is inconsistent with scientific understanding (Keeley, Eberle & Farrin, 2005). Often, explanations in biology are counterintuitive to students. For instance, students incorrectly believe that when the lungs inflate the chest expands. The accurate explanation is that when the chest expands the lungs inflate. When I am teaching the respiratory system, I must take this into consideration or students will maintain their inaccurate thinking even after instruction. A teacher must take the prior knowledge of the students into account. Otherwise the students may resist the scientific explanation. These barriers to learning may exist in students at all grade levels. Determining prior knowledge of students will help the teacher customize lessons to improve student learning. Assessment examples in this article are called "probes" and are, for the most part, formative or diagnostic in nature. The probes are assessments "for learning, not assessments of learning" (Keeley, Eberle & Farrin, 2005, p. 3). Probing strategies will:

- help students understand their own learning
- reveal students' misconceptions
- help students build a more coherent, holistic conception of life science concepts (AAAS, 2005).

If students are not engaged in their own learning, "they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside of the classroom" (Bransford, Brown & Cocking, 1999, p. 14). Science content is often taught as isolated pieces of information. Students need to learn the holistic conception of life science concepts; science is a set of larger concepts with many associated facts (NSTA, 2002).

Special Considerations for Science Instructors

Before adopting any particular instructional innovation, science instructors must adapt the strategy to meet the needs of the particular student population in their school context. As expected, science learning expectations vary greatly among and across college science courses (Bilica, 2004). The variances occur due to factors, such as the nature of the institution (private or public, large or small) and the audience for the course (science majors or non-majors). "No size fits all" is applicable to science instruction. The three probing strategies described in this article can be used effectively in a variety of contexts; however, we encourage instructors to consider ways to adapt use the strategies to meet the needs of their own students and courses (NSTA, 2002). The aim of this article is to provide support for science instructors who wish to implement new strategies to probe student understanding, not to prescribe a single best way to conduct a science course.

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The Strategies

The following paragraphs contain examples of probing mechanisms I have used to determine my college students' prior knowledge and thinking during instruction. I have used these strategies in classes with 40 to 50 students, but the strategies can be effectively used in larger classes. This past spring, I focused on building a curriculum based on the prior knowledge of students in a freshman level Human Anatomy and Physiology Course. I teach in an urban northeastern four-year Jesuit liberal arts college with 4,000 students. Even though the course is an undergraduate course, the concepts were developed for instructional parity with the *National Science Educational Standards* (NRC, 1996) for ninth to twelfth grade. In this article, the three probing strategies are described and their uses explained. These strategies include:

1. pre-instructional graphic models (overhead transparencies of figures, graphs, or tables)
2. concept maps
3. student-generated questions

Pre-Instructional Graphic Models

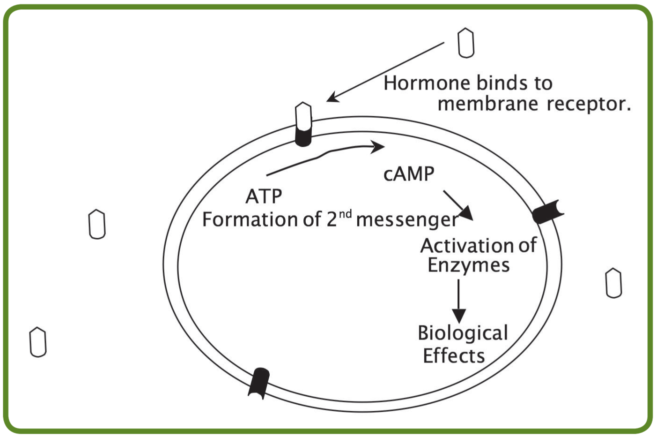
My first example of a probing strategy is the use of graphic models as part of a warm-up, pre-instructional activity. Teachers use graphic models to describe concepts to students during instruction or to summarize a topic. During class, I use overhead transparencies of figures, graphs, or tables as prompts to find out what the students knew. For example, I begin teaching about the endocrine system by asking the students to mechanistically describe the process occurring in the drawing seen in Figure 1. Figure 1 is a model illustrating receptor-cellular interaction which illustrates "regulation of an organism's internal environment and changing physiological activities to keep conditions within the range required to survive" (NCR, 1996, p.157). Previously in the course, students learned about receptor-cellular interaction in the context of cellular anatomy, neurotransmitter regulation, and activation of muscular contraction.

A mechanistic description (a cause-and-effect description) was taught earlier in the course. An example of a mechanistic description of the figure is as follows:

> The hormone binds to the membrane receptor. When the hormone and receptor bind, ATP is transformed into cAMP. Cyclic AMP (cAMP) causes enzymes to be activated. The activated enzymes produce biological effects.

I ask the students if this mechanism is similar to one they learned before, and if so, what the similar mechanism was. Following a learner-centered discussion of the various mechanistic descriptions, I ask the students the following question: *What are the factors that influence target cell activation by hormone-receptor interaction?* Students' answers include hormone concentration, enzyme availability, and number of receptors. The factors that influence the hormone-receptor interaction are comparable to other cell receptor interaction that was previously learned. The key to assessing students' prior knowledge is to engage students in dialogue and to take note of what students say (Michael & Modell, 2003). By using this strategy, I assess students' prior knowledge of cellular activity, and students learn what they know about cellular activity. They realize whether their thinking is accurate and complete and if they can use it to explain the interaction between hormones and cells.

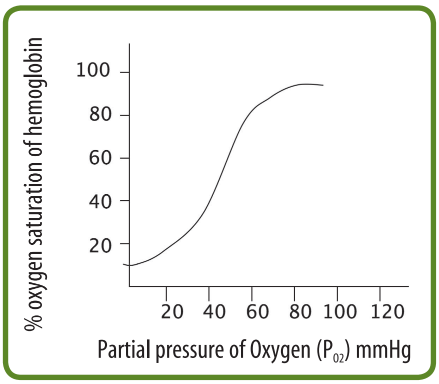
Figure 1. Hormone Receptor Interaction



Another example of a probing tool is the use of a graph or table. Science as inquiry "is a step beyond 'science as a process,' in which students learn skills, such as observation, inference, and experimentation" (NRC, 1996, p. 105). To introduce the complex concept of how changes in oxygen pressure cause changes in the binding affinity of oxygen and hemoglobin, I use the oxygen hemoglobin saturation graph (Figure 2). Previous class time has been devoted to talking about red blood cells, the hemoglobin molecule, and oxygen binding sites on the hemoglobin molecule. Instead of explaining the graph to the students, I ask the students for an explanation of the graph in their own words. This is a good group activity.

Students need more practice at interpreting graphs and figures. The oxygen hemoglobin saturation line graph is similar to many line graphs in biology. In the oxygen hemoglobin saturation graph, there is a steep slope indicating a rapid rate of change and then the slope plateaus, indicating very little change. The students wrote that between 40 and 60 partial pressure of oxygen, there was about a 20% change in saturation (saturation had been defined), but between 80 and 100 partial pressure of oxygen, there was very little change in percent saturation. After this exercise, I asked the students to think about why the graph plateaus. Why is there a steeper slope between 40 and 60 mmHg? Hemoglobin is a protein molecule that changes configuration with changes in the partial pressure of oxygen. The concept of protein configuration change caused by changes in various factors, such as pH, amount of reactants, and temperature, is an important concept in cellular biology (NRC, 1996). By starting instruction with students interpreting the oxygen hemoglobin saturation graph, the students are able to understand how the change in the partial pressure of oxygen affects the binding affinity between hemoglobin and oxygen. I find students are better able to answer prediction questions, such as what happens to oxygen hemoglobin saturation at high altitude and why. We next discuss how this change in

Figure 2. Oxygen hemoglobin saturation curve



binding affinity is beneficial for the body. I still use the instructional tools I used in the past (hemoglobin oxygen saturation curve), but now I start with students' interpretations of graphs to help the students understand oxygen hemoglobin saturation.

Concept Maps

Another probing mechanism is the use of concept maps. Concepts maps are useful tools to evaluate the way students organize and represent knowledge. If concept maps are used pre- and post-instruction, changes in students' knowledge and understanding can be assessed. Even though concept maps have been used extensively as summative assessments, I use concept maps as formative assessments to determine students' thinking. Before I ask students to create concept maps, I teach a short lesson on map construction. I prefer to use Novak's (1990) concept map formation procedure. The maps should be constructed to show the order and connection of concepts. The most comprehensive, most general concepts are at the top of the map. The more specific, less general concepts are displayed at the bottom. "Cross-links" are another important characteristic of concept maps. The "cross-links" represent relationships between concepts. Novak (1990) believes that when students gain new knowledge, cross-links often indicate resourceful use of that new knowledge by the student. The success of concept maps depends on:

1. who creates the concept map (student or teacher)
2. when and how often it is used in instruction
3. how much information is included about the relationships between concepts
4. how the map is used in assessment (Mintzes, Wandersee & Novak, 2000)

When concept maps are used as an assessment, students are encouraged to use meaningful learning patterns (Novak & Gowin, 1984; Novak, 1990; Mintzes, Wandersee & Novak, 2000).

Figure 3. A concept map of the digestive system.

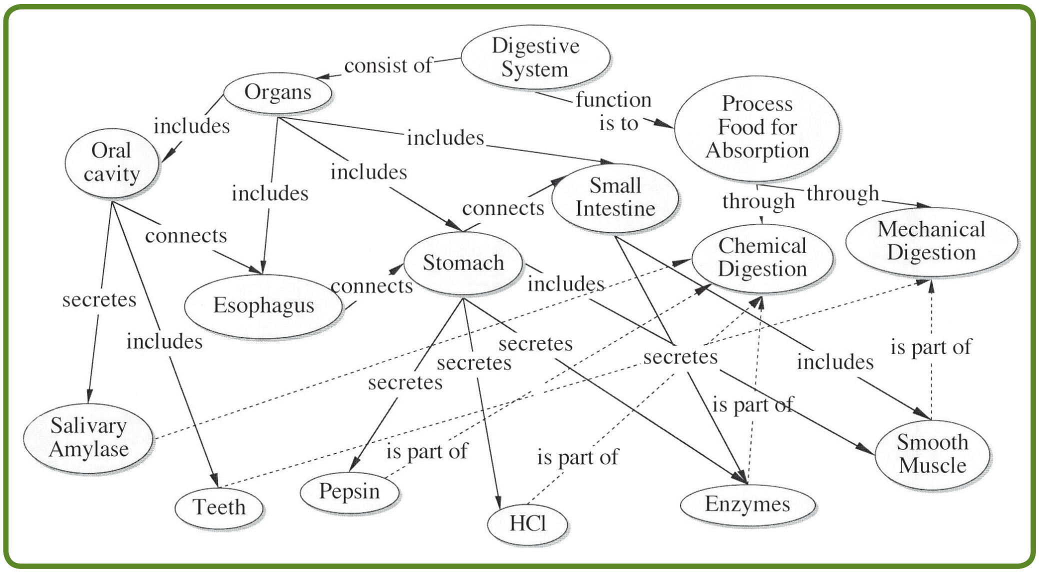


Figure 4. Student A's concept map of metabolism.

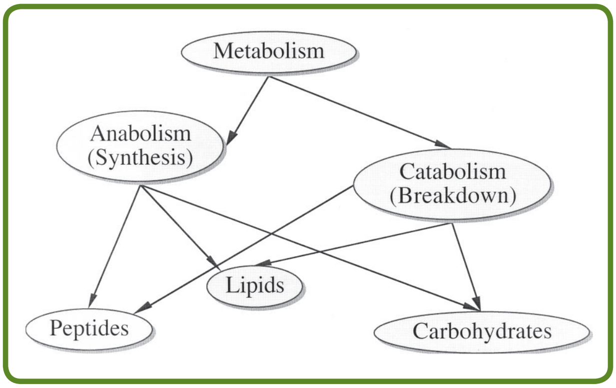
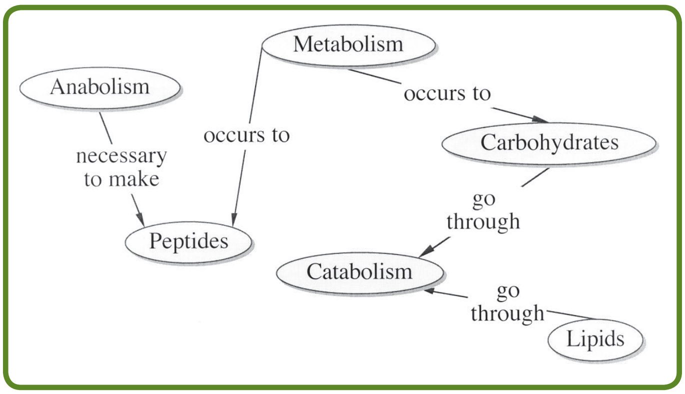


Figure 5. Student B's concept map of metabolism.



Concept map construction must be based on a learning goal or objective. The learning goal for the concept map of the digestive system is for students to understand the characteristics of structures and various functions. Figure 3 is a concept map of the digestive system. I share it with the students as an example of a concept map generated after students have studied the digestive system. Thus, it gives them an example of a meaningful concept map.

Prior to studying the Metabolism and Energy chapter, the students are asked to create a concept map using the following terms:

Carbohydrates
Absorption
Catabolism
Anaerobic
Peptides
Metabolism
Anabolism
Aerobic
Lipids

The concept maps produced by the students help them to think about what they know about metabolism and energy and provide the instructor insight into what the students know about metabolism and energy. Having the students create a concept map (in groups or individually) prior to instruction engages them in learning the concepts. This approach is different than the traditional approach of lecturing on a concept without giving the students the opportunity to reflect on what they know. Figures 4 and 5 are examples of concept maps created by Student A and Student B respectively.

Although Student A used no cross-link terms, Student A's concept map is an example of an accurate map showing correct connection of the terms; therefore, Student A has some understanding of metabolism. Student B accurately indicates that lipids and carbohydrates are broken but does not show lipid and carbohydrate synthesis. It is possible that Student B thinks metabolism includes only molecular breakdown and not synthesis. Instruction must emphasize that metabolism is catabolism (molecular breakdown) and anabolism (synthesis). After instruction, I give a post assessment to determine whether Student B includes synthesis in the definition of metabolism. Concept maps promote meaningful learning; students assimilate new knowledge with prior knowledge instead of simply memorizing concept definitions.

Student-Generated Questions

Allowing the students to ask their own questions can be used as a probing mechanism. Chin (2001) suggests "there is substantial educational potential in student-generated questions in directing students' inquiry and guiding their construction of knowledge" (p. 4-5). Chin (2001) describes two types of questions: basic questions and wonderment questions. The basic questions are superficial learning questions, for instance, "What is the name of the major vessel that carries blood from the left ventricle of the heart?" The correct answer, aorta, does not stimulate any further discussion on the topic. An example of a wonderment question is "What happens to the pressure in the aorta if the elastic fibers in the vessel lose compliance?" This question promotes discussion about the circulatory system (NCR, 1996, pg. 156-157, 173). If a student understands the question and knows the answer, he/she can understand a possible cause of high blood pressure or hypertension, which is a health issue. When students are expected to create wonderment questions, their understanding of concepts improves. From the students' discussion of the answers to wonderment questions, an instructor can determine students' understanding and frame instruction around what students know.

I give a homework assignment to write a question about the influence of plasma carbon dioxide concentration on respiration. To make sure my students come to class ready to engage in learning science, they need incentives. The incentive for writing a wonderment question was one class participation point. Participation points are 20% of the student's total grade. The participation assignments are graded for the quality of the student's ideas rather than correctness. A few students write basic information questions, such as what happens to respiratory rate if carbon dioxide increases? (The answer is respiratory rate increases.) However, the same question can be reworded to make it a wonderment question. When a swimmer holds her breath, her carbon dioxide concentration increases. Explain what happens to a swimmer's carbon dioxide concentration when she holds her breath during a 50-meter sprint and explain why it happens. The students show what they know by writing wonderment questions.

At the end of class period, I often ask the students to write a question about what they did not understand during the period. This has been very helpful, and frequently I find that many students are confused about the same concept. It also has been a great way to connect the content covered in class with the content to be covered during the next class.

Conclusion

To help a student learn, the instructor must understand what the student knows prior to instruction. By knowing what the student understands about a new topic, teacher's instruction helps the student build on prior knowledge and make the necessary conceptual change needed to meet the instructional goals. It is also necessary for the teacher to know the students' misconceptions so those misconceptions can be addressed. In addition, Sungur, Tekkaya & Geban (2001) state, "Teachers should be aware of students' prior knowledge and misconceptions, because they are strong predictors of student achievement in science ..." (p. 98). In an article about misconceptions, Arnaudin & Mintzes (1985) suggest that teachers and textbook authors fail to highlight "those concepts that are most intransigent, many times overlooking the necessity of challenging firmly entrenched ideas" (p. 730).

There are many ways to assess what students know. Often, many students have the same alternative understanding about a concept introduced in a course. By teaching the same course every year, common alternative understandings become obvious. Therefore, if instruction addresses common alternative understandings, it promotes meaningful learning for more than one student. The goal of teaching science should be to help all students form a more correct basic understanding of the scientific issues they will encounter, not to make all students science researchers. To achieve this goal, learning must start with what the students already know.

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