DRAWING OUT MISCONCEPTIONS

Assessing student mental models in biology

William J. Hoese
Merri Lynn Casem
Department of Biological Science
California State University, Fullerton
March 2007

Goals and Objectives

The goal of our project is to develop an image-based instructional tool that would also function as a formative assessment for both students and faculty. This "tutorial assessment" will be based on research into student mental models of core biological principals. Student-generated drawings and image recognition tasks will be used to identify common misconceptions and areas of conceptual weakness within the population of beginning biology majors. The tutorial assessments will be implemented in the two of the four lower division core courses. The conceptual domains that will be included in this initial phase of our project will be biodiversity and cellular structure/function. The use of images allows for an assessment of student knowledge independent of English language proficiency.

Background

The ability to interpret and construct images are core skills students must master in order to understand the "big ideas" in biology. For example, identifying appropriate inputs and outputs to biological systems, understanding phylogenetic hypotheses, and accurately depicting biological structure/function relationships typically rely on images to represent key components and concepts. Introductory biology textbooks contain innumerable figures and pictures designed to illustrate biological structures and processes and, as faculty, we expect students to be able to gather useful information from these figures. Scientists perform exceedingly well on standard tests of spatial ability, thus professional biologists may not even realize students possess misconceptions about biological images. Yet, image-based assessments are powerful research and instructional tools. They can provide insight into what students understand and, perhaps more importantly, what they misunderstand about topics in science (Halloun, 1996; Wandersee, 2000; Nicoll, 2001) thereby enabling instructors to identify misconceptions and students to monitor their own progress in learning new material.

Student-generated images are useful in identifying the mental models that students hold about concepts. For example, drawings by children of what is inside of them indicate awareness of a wide diversity of organs and their location, but in younger children, these organs are not connected to one another whereas older children connect organs into functional units and organ systems (Reiss *et al*., 2002). Similarly, student drawings in the areas of geology and chemistry can provide useful insight into common misconceptions (Nicoll, 2001; Sibley, 2005). Thus, by using simple drawings, instructors can gather large amounts of data on the mental models students have about scientific concepts.

Drawings in and of themselves are models of concepts and understanding how and when to apply them are important skills. Students with basic understanding of a visual concept may reproduce a drawing in the same style as they have observed in their textbook, indicating that they have not generalized the concept and "made it their own." Students learning cell biology may reproduce the iconic representation of a cell as it appears in the text, drawing the shape and positioning each structure in the same way as they observed in their textbook. Thus, student drawings, even when correct, may contain features that indicate an incomplete understanding of material because of how students represent structural components, or for the case of organismal diversity, gross morphology or bauplan.

Summative assessments of student knowledge such as quizzes, exams and practicums can be seen as sharing the common features of requiring students to make inferences and apply their knowledge within a defined context or problem. Student misconceptions lead to diminished performance on these measures of learning; therefore it is likely that a connection exists between the process of inferential reasoning and misconceptions.

Current models of human inferential reasoning invoke the concept of "bounded rationality" the idea that the decision-making process must occur within a finite amount of time making use of limited set of knowledge (Chase *et al.,* 1998). According to these models, the first step in any decision-making task is a **recognition heuristic**, identifying whether the item under consideration is familiar or unfamiliar. If the item is familiar, then the individual accesses prior knowledge in the form of **cues** to further discriminate. If the item is unfamiliar then the individual simply guesses – without use of any cue set. The use of cues for discrimination between two items or for the categorization of a single item is thought to follow a **fast and frugal heuristic** called "Take the Best" algorithm. Under this model, inferential reasoning utilizes the best, most valid cue, ignoring all others, to quickly arrive at a correct decision (Gigerenzer and Goldstein, 1996). Errors in decision-making arise when the cue applied to the task does not meet the standard of "best and most valid." We are proposing that misconceptions represent students using either <u>incorrect cues</u> or correct cues that are <u>insufficient</u> for the required task. For example, given the task of categorizing whether an image belongs to the set "insects," some students employed the incorrect cue "insect = many legs attached to the *abdomen,*" while other students used the insufficient cue "insect = *terrestrial* arthropod" (Hoese and Walker, in review).

The recognition and replacement of misconceptions required for deep learning would then represent the revision or elimination of incorrect cues (*six legs attached to the thorax* replaces *many legs attached to the abdomen*) and the acquisition of new, more valid cues (*six legged terrestrial or aquatic arthropod* replaces *terrestrial arthropod*). The cognitive dissonance required to trigger the replacement of incorrect or insufficient cues are effective in the context of an inferential reasoning tasks that provide immediate feedback (NRC, 1999). It is the goal of this project to create assessments that will engage students in inferential reasoning and will provide immediate feedback to positively influence and improve the student's cue repertoire.

<u>Development Process</u>

The development of the tutorial assessments will be the product of two lines of investigation (see Fig1). We will use student-generated drawings to determine the scope and variation in student mental models of various core concepts related to biodiversity or cellular structure/function. Student drawings can be captured using an electronic whiteboard that allows us to capture both the drawing and the student's narration of their drawing. The second investigation will use an image-recognition task that requires that students examine a "doctored" image and decide if the image is representative of a specific concept. The recognition task challenges the student's conceptual knowledge by requiring that they draw upon the cue sets they possess in order to make decisions about the quality or other characteristics of the image.

<u>Planned sampling</u>

The demographics of CSUF make it an excellent venue for this project due to its large number of non-traditional and diverse student population. CSUF is an accredited and federally designated post-secondary minority-serving and Hispanic-serving institution. Data for fall 2005 reveal that 27% of CSUF undergraduate students list themselves as Hispanic, 22% as Asian, Pacific Islander and Filipino, 32% as white, 4% as African American, 4% as International, and 0.5% as native American. Its enrollment of approximately 9,000 Hispanic students makes CSUF one of the largest Hispanic-serving institutions in the nation. Approximately 60% of CSUF students are female and nearly one-third were born outside the United States; 13% come from families in which neither parent graduated from high school and 51% come from families in which neither parent graduated from college (http://www.fullerton.edu/analyticalstudies/student_profiles.asp). The average age of our undergraduates is 23 years and over 15% of the undergraduate population report having at least one dependent. Most compelling in the context of this proposal, 48% of our students spoke a language other than English at home when they were young.

This project will take place in the context of two, lower division courses for biology majors at California State University Fullerton (CSUF) an urban, four-year comprehensive university located in Orange County, California. Biology 171 *Biodiversity and Evolution* and Biology 172 *Cellular Basis of Life* serve a population of beginning biology majors, community college transfer students, and a limited number of non-major (general education) students. The principal investigators for this project are instructors of these courses, thereby ensuring access to the student population. Preliminary analysis of student-generated images and recognition tasks will be completed using a subpopulation (50 students/course) of students. Implementation of the tutorial assessment and evaluation of its instructional impact will be made using the full enrollment of the classes (approx 220 students/course).

<u>Progress</u>

We are at the beginning of this project. We have preliminary data on student mental models of cell and membrane structure. We also have data on student recognition as well as mental models of insect biodiversity. A preliminary version of the tutorial assessment has been implemented in one of the courses (Casem, 2005).

<u>Student-generated Images: Biodiversity at the Cellular Level</u>

Undergraduate biology majors manifest a range of understanding and misunderstanding related to the concept of cellular structure. In this assessment, students were asked to generate a drawing representing their idea (one form of their mental model) of a cell (n=234). The vast majority of students produced an image; however, their drawings were either *insufficient* (possessing correct, but incomplete, information), *incorrect* (possessing wrong information), or *iconic* (reproducing a textbook image) (Figure 1).

<u>Student Recognition/Decision Task: Biodiversity at the Organismal Level</u>

We developed a preliminary assessment that used line drawings to ask (1) what types of organisms do students categorize as insects, and (2) which morphological features are important to students when deciding whether an organism is an insect? Introductory biology majors (n = 260) viewed line drawings of animals and determined whether or not each image was an insect. Line drawings included twelve insects, twelve non-insect arthropods, and twelve non-arthropod animals. In a related task, students examined a series of digitally manipulated images and were asked to identify any incorrect features of the drawings (Figure 2). If the drawing did not match their idea of an insect, then students were prompted to describe what was wrong with the drawing. A diverse cross-section of taxa were used in this assessment including manipulated examples of a dragonfly, moth, wasp, ant, termite, beetle, and spider in which the external morphology was modified by adding, moving or removing legs, tagma, wings, and antennae.

Students identified insects as insects correctly the vast majority of the time. Students were highly likely to identify non-insect arthropods (*e.g.*, spider, scorpion, mantis shrimp) as insects, but did not tend to identify non-arthropod animals (*e.g.*, earthworm, snail, raven) as insects. The results of the manipulated images assessment suggest a similar pattern. Students did quite well with insect images having correct morphologies but did not do well identifying images with incorrect insect morphologies. These data suggest that students often use cues that lead them to over-generalize the features that define an insect, which works well when the object is an insect, but fails when considering other non-insect arthropods (*e.g.*, spiders, ticks, and crustaceans). By presenting students with diverse images and images with specific features altered we are identifying the cues students use in their own mental models of these visual concepts. Thus, by using a set of images, we were able to gather information on the range of misconceptions and identify some of the morphological characteristics that students are using to make classification decisions.

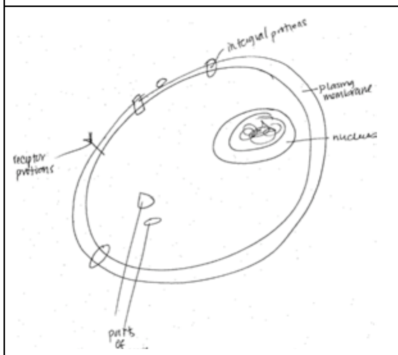
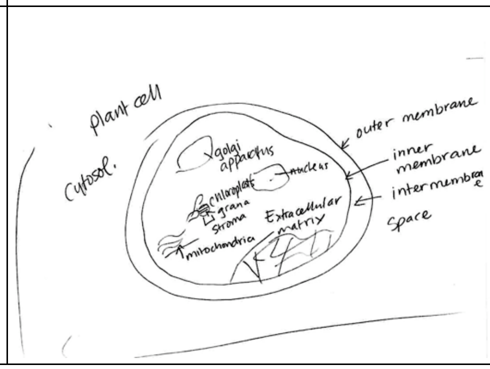
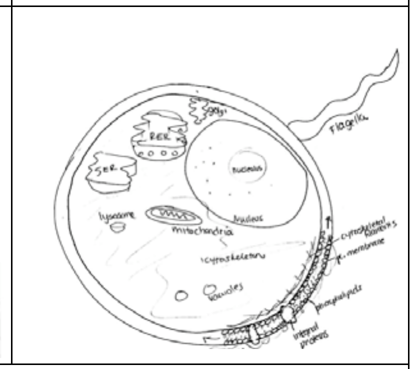
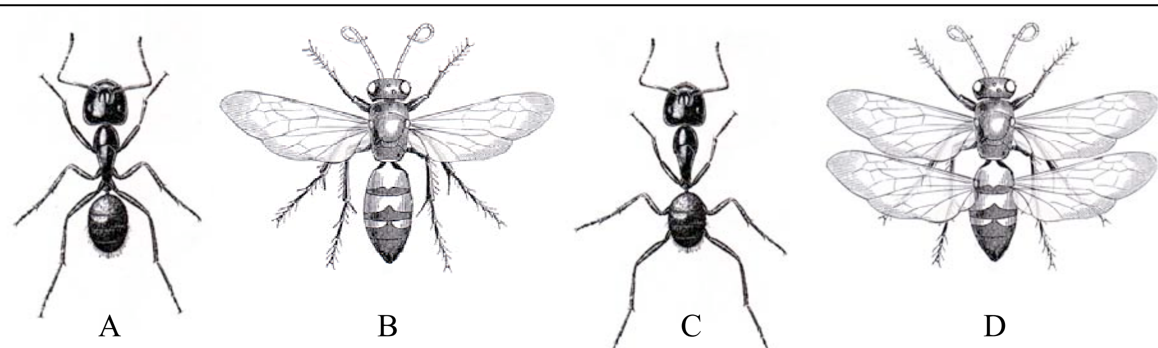
Insufficient	**Incorrect**	**Iconic**
		

Figure 1. Students were asked to diagram a cell. Resulting drawings fell into three major groups. **Insufficient** drawings lacked detail of essential components of the concept. The cell possesses a plasma membrane (including various membrane proteins) and a nucleus, but lacks internal organelles. **Incorrect** drawings depicted misplaced or poorly represented structures (extracellular matrix contained within the plasma membrane, mislabeling of membranes, Golgi apparatus represented as a single organelle). **Iconic** drawings, although produced independently, contained strong similarities to textbook diagrams, indicating students lack a deeper understanding of the concepts and are reproducing features by rote memorization.



A B C D

Figure 2. Examples of insects used to identify student misconceptions. A & B. Hymenoptera with appropriate insect morphology. Images were manipulated to clearly depict the number and position of limbs, wings, antennae, and tagma. C. Hymenoptera with incorrect morphology. All legs have been digitally manipulated and moved to more posterior positions. D. Hymenoptera with additional wings positioned on the abdomen. Images modified from Beverley and Ponsonby, 2003.

Literature Cited

Casem, M.L. 2005. Concept Coach: An online activity that addresses student misconceptions and supports learning. Accepted for publication in Exchanges – The online journal of teaching and learning in the CSU (http://www.exchangesjournal.org/classroom/1211_Casem.html)

Chase, V.L., Hertwig, R., Gigerenzer, G. 1998. Visions of rationality. Trends in Cognitive Sciences 2:206-214.

Gigerenzer, G. and D. G. Goldstein. 1996 Reasoning the fast and frugal way: models of bounded rationality. Psychological Review 103: 650-669

Halloun, I. 1996. Schematic modeling for meaningful learning of physics. Journal of Research in Science Teaching. 33(9): 1019-1041.

Hoese, W. J. and S. E. Walker. In Review. Using image-based assessments to identify misconceptions of insect diversity in college students. International Journal of Science Education.

National Research Council. 1999. How people learn: Brain, mind experience and school. Committee on developments in the science of learning. Commission on behavioral and social sciences and education. National Academy Press, Washington, D.C.

Nicoll, G. 2001. A report of undergraduates' bonding misconceptions. Int. J. Sci. Educ. 23(7):707-730.

Reiss, M.J., Tunnicliffe, S.D., Moller Anderson, A., Bartoszeck, A., Carvalho, G.S., Chen, S., Jarman, R., Jonsson, S., Manokore, V., Marchenko, N., Mulemwa, J., Novikova, T., Otuuka, J., Teppa, S., and Rooy, W.V. 2002. An international study of young peoples' drawings of what is inside themselves. Journal of Biological Education. 36(2): 58-63

Sibley, D. F 2005. Visual abilities and misconceptions about plate tectonics. J Geoscience Education. 53 (4):471-477.

Wandersee, J.H. 2000. Designing an image-based biology test. In: Mintzes, J.J., J.H. Wandersee, and J.D. Novak eds. Assessing Science Understanding. Academic Press, San Diego, CA.

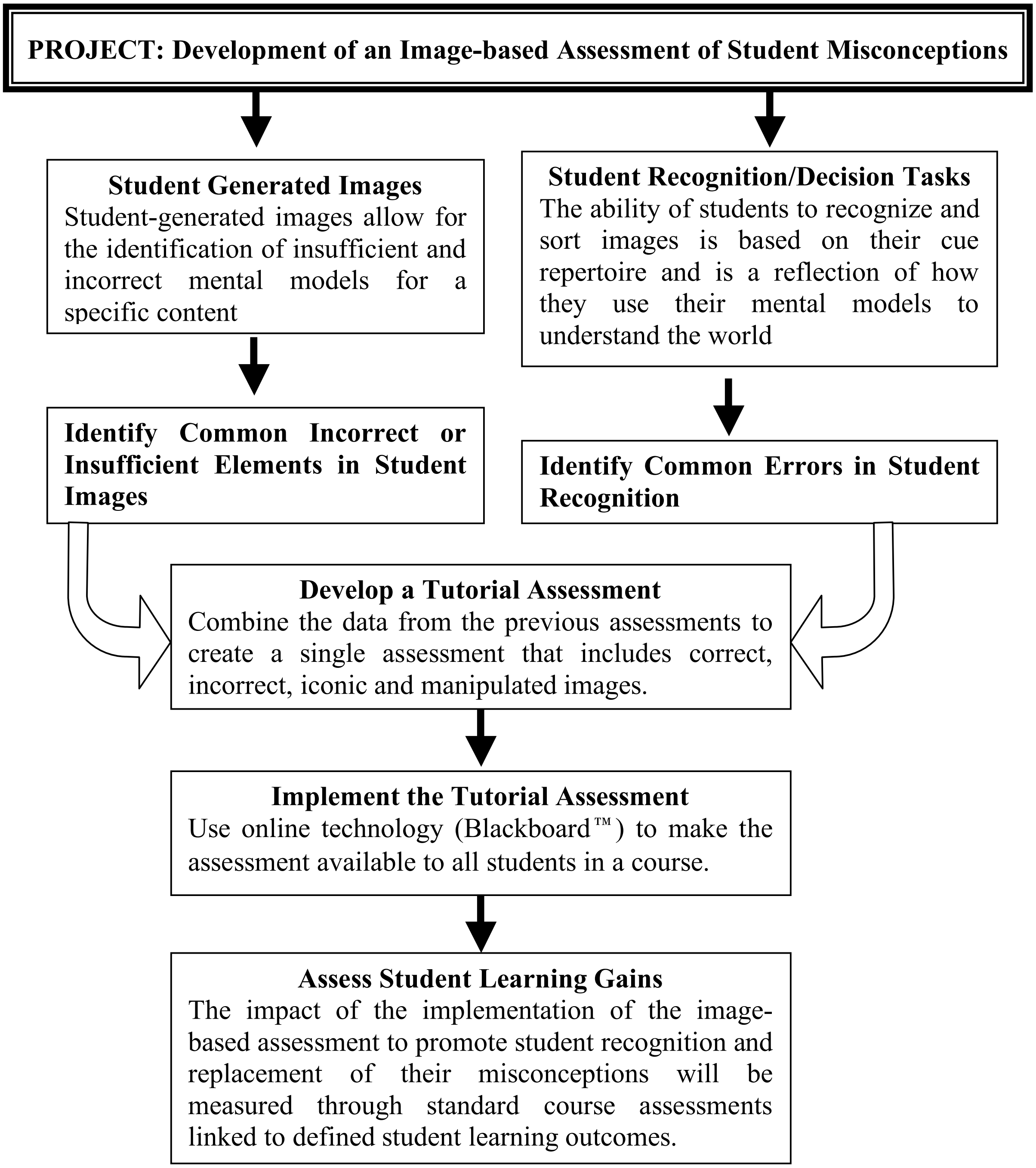


FIGURE 3 – Overview of the stages of the development of a tutorial, image-based assessment.