Novel assessments: detecting success in student learning

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How can we gather evidence that shows that all students understand the concepts and processes of science? This question is central to the idea of "scientific teaching" (Handelsman *et al.* 2004). As scientists, we learn to question anecdotal data and to challenge our peers to use multiple procedures to collect reproducible results. A similar approach is possible when assessing students' knowledge about a topic. This article illustrates how multiple methods can be used to assess student understanding of the "novel weapons hypothesis" presented in the Callaway and Ridenour review of theories regarding invasive plant species (see pp 436–443). The paper introduces students to concepts of natural selection, fitness, competition, and invasion of exotic species. The assessments we describe here engage students in diverse ways to demonstrate their understanding.

Multiple and varied assessments give students feedback about their progress, help instructors to determine their next instructional steps, and communicate to students what they need to know and do, and motivate them to continue challenging themselves to learn (Pellegrino *et al.* 2001). Learning through assessment offers students ways of building their understanding by using models, theories, and "cause and effect" explanations that support successful knowledge transfer (Mayer *et al.* 1996). The use of multiple representations, such as definitions, analogies, visual models, and examples, helps students to understand and remember scientific concepts, while allowing them and the instructor to assess their understanding. The "novel weapons" paper provides students with opportunities to build a deeper understanding of basic biological concepts and develop problem-solving skills, as they explore theories and hypotheses about plant invasions.

Student learning goals

Students will:

- Describe factors that cause differential growth or reproduction in plants
- Predict ways in which plants affect one another
- Propose and explain traits that would convey competitive advantages to invading species
- Design an experiment to test two hypotheses about control of plant growth

Faculty teaching goals

Instructors will:

- Use multiple forms of assessment (eg probing knowledge, paired questions, concept maps, and solving an experimental problem) to help recognize how well students understand scientific concepts
- Provide students with guidance and practice in using different forms of assessment, such as concept maps (Pellegrino *et al.* 2001)

Instructional design

Students read the Calloway and Ridenour paper as homework, focusing on the learning goals noted above. This instructional design alternates assessments used inside or outside the class with short lectures or discussions. Just as research results direct scientists to their next experiments, student responses obtained in these assessments inform subsequent discussion or lecture segments.

Assessment 1. A knowledge probe shows students' understanding about the cause of variation in plants. Use an illustration or photo of a small plant and a large plant. Inform students that these plants are growing in the same habitat, in the same population, and are the same age. Ask students to write for 5 minutes, explaining at least three factors that might cause the difference in sizes between the plants. Student groups then discuss responses and selected groups report their ideas. Information gathered from this initial knowledge probe is used to direct subsequent instruction.

Assessment 2. Paired questions query students' understanding about origins of variation. A multiple choice question about the process of evolution is followed by a written response asking for *a rationale* for the answer to the multiple choice. This will allow instructors to identify knowledge gaps. For example:

Part A. According to the process of natural selection, how did exotic plants most likely come to produce novel toxic biochemicals that improved their competitive ability when they invaded a new habitat?

(a) Invading exotic plants needed to change in order to survive, so beneficial new traits developed.

(b) Variations in exotic plant chemicals occurred by chance, and exotics producing chemicals that reduced the success of competing natives produced more offspring.

(c) Mutations occurred in the invading exotics so they could adapt and succeed in the new environment.

(d) Differences between the exotic and native environ-

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ments caused production of different chemicals by exotic and native plants.

Part B. Give one reason each for rejecting the three responses you did not choose.

Ask students to show their answer to the multiple choice question by raising their hand, voting with a numbered note card, or using a personal response system. Then, after short discussions, individuals or groups of students should explain the problems with the erroneous responses, and use comments to clarify the correct concepts.

Assessment 3. Concept mapping asks students to link ideas about evolution and interactions among plants. Concept maps (Panel 1) are illustrations of relationships among concepts organized hierarchically (Novak 1998). Tools such as concept maps, flow charts, and Venn diagrams reveal student understanding about associations and organization of many concepts, elements not easily assessed by multiple choice questions, or even extended responses. Knowledge diagramming tools like concept maps enable students to organize and retrieve ideas, then construct new knowledge and link it to their prior knowledge. The ability to connect seemingly disparate terms and ideas is one of the skills that distinguishes expert from novice problem solvers (Novak 1998). A meta-analysis of 19 studies revealed that concept mapping had positive effects on student achievement and attitudes toward science (Horton *et al*. 1993), although constructing concept maps requires practice throughout a course. Key concepts from Callaway and Ridenour include: competitive advantage, natural selection, fitness, growth, survival, reproduction, exotic species, native species, limiting resources, and novel phytochemical weapons. The instructor then reviews the maps, identifies incorrect links, and learns what students consider relevant, accurate relationships and the hierarchical organization of concepts. Students can add new concepts to their maps throughout a course, making new connections.

Assessment 4. An experimental problem allows students to show their understanding of experimental design and the complexity of interactions and selection pressures. Students are asked to design experiments to test hypotheses from the paper about the control of plant growth. This could be written homework (individual) or a written in-class problem (group activity) with assessment by the instructor and/or peers. For example:

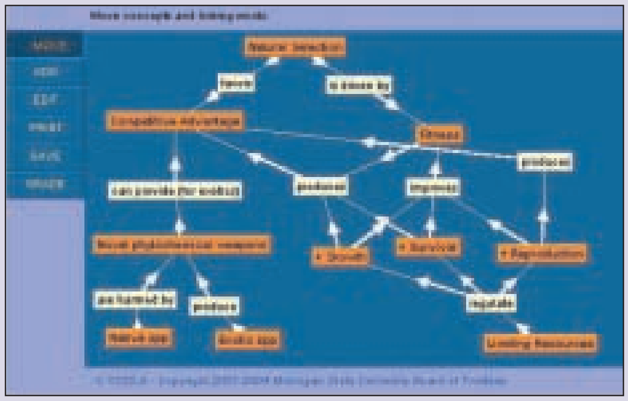
Part A. Design greenhouse experiments to test two hypotheses from the reading:

H1: Chemical exudates of an exotic species, such as knapweed, reduce performance (or fitness) of native species.

H2: Exotic species out-compete native species in acquiring essential nutrients, such as nitrogen and phosphorous.

Part B. Assume that your results provide support for Hypothesis 1, showing that by exuding novel phytochemicals that inhibit native plant growth, exotic plants out-compete natives. Now imagine you repeat the experiment in a field plot and find that natives grow and/or reproduce as well as or better than exotics! Propose three possible reasons, related to factors affecting fitness, for your field results.

Panel 1. Instructions for building concept maps



(1) Write each concept on an individual index card or small post-it note, or use web-based applets such as http://ctools.msu.edu (See http://cmap.ihmc.us/)
(2) Arrange the concepts so the general ideas appear above the sub-ideas
(3) Add linking lines and then add linking verbs that explain the relationships between the concepts

Final note

Callaway and Ridenour review concepts proposed to explain relationships among native and invading species that have long challenged scientists, and also present an engaging storyline that will capture and hold the interest of undergraduates. Multiple assessments inform instructors *and students* about their progress towards understanding. With these data, instructors can direct their subsequent instruction.

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References

Handelsman J, Ebert-May D, Beichner R, *et al*. 2004. Policy forum: scientific teaching. *Science* **304**: 521–22.

Horton B, McConney AA, Gallo M, *et al*. 1993. An investigation of the effectiveness of concept mapping as an instructional tool. *Science Education* **77**: 95–11.

Mayer RE, Bove W, Bryman A, *et al*. 1996. When less is more: meaningful learning from visual and verbal summaries of science textbook lessons. *J Educ Psychol* **88**: 64–73.

Novak J. 1998. Learning, creating, and using knowledge: concept maps as facilitative tools in schools and corporations. Mahwah, NJ: Lawrence Erlbaum Associates.

Pellegrino J, Chudowsky N, Glaser R (Eds). 2001. Knowing what students know. Washington, DC: National Academy Press.