Unleashing problem solvers: from assessment to designing research

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"Can transgenes be kept on a leash?" ask Marvier and Van Acker in the preceding review article (pp 93–100). "No", they answer, "the movement of transgenes beyond their intended destination is a virtual certainty", and furthermore "it is unlikely that transgenes can be retracted once they have escaped". Would these bold statements engage students, revealing the realities and complexities of genetically modified (GM) crops? How can we use the critical analyses presented by these authors to guide our undergraduates towards developing their own analytical skills?

Students' abilities to analyze controversial subjects are often limited by their lack of understanding of basic science fundamental to the issue. In this case, their approach to the debate about GM crops may be driven by common misconceptions about, for example, gene expression, traits, or even the difference between an allele and a mutation. Students may not know that genes flow between non-GM crops, a normal, commonly occurring process. Hence, a common belief is that traditional methods of crop breeding are completely safe, while all transgenic crops are potentially dangerous (Beringer 2000; CSU 2004). Ideally, we want students to understand the body of knowledge surrounding a subject so they can transfer and apply their knowledge to solve novel, complex problems. In this two-step approach to scientific teaching, we use Marvier and Van Acker's paper as the context for assessing students' comprehension and problem-solving abilities. We then provide instructors with a framework for thinking about what these assessments mean and how they could form the basis of a researchable question.

Student goals

- Demonstrate understanding of biological principles relevant to genetic modification of crops.
- Explain the pathways and processes of gene flow from GM crops to other plants.

Instructor goals

- Probe student understanding of concepts fundamental to GM technology and, based on the student responses, design instruction that addresses student needs.
- Use data from student assessments to pose a significant question about their learning that can be investigated empirically.

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First step: students move from comprehension to problem solving

The following questions are designed to check students' knowledge and comprehension of biological principles after they read the paper. Questions are derived directly from the content in Marvier and Van Acker and are generally known concepts that are difficult for students to understand.

Knowledge and comprehension questions

Students could support each response with an example to demonstrate deeper understanding.

- What is a gene? A transgene?
- What is a trait? (eg ultimate source [DNA], expression [protein], transfer from generation to generation [reproduction/meiosis])
- How does an allele differ from a mutation? A transgene?
- How can the genotype of an organism influence the phenotype?
- What does hybridization mean? (eg crop/weed, GMO crop/non-GMO crop hybridization)
- What is gene flow? Dispersal?
- How does sexual reproduction occur in plants?
- Do transgenes and mutations have selective advantage?

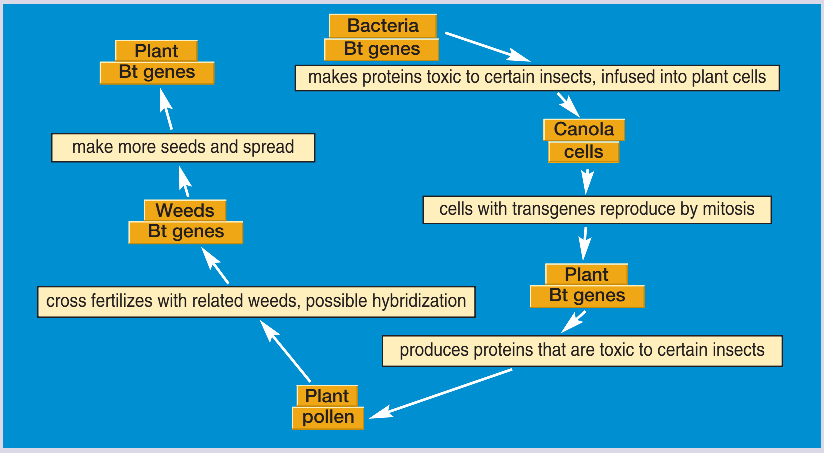
While comprehension of the facts above is important for thinking and problem solving, students also need opportunities to work on problems that allow them to build connections between concepts that help them gain long-term understanding (Anderson and Krathwohl 2001). Rather than suggest a specific instructional design, we recommend having students work in groups to address some of the comprehension issues revealed by their responses to the questions above. Box models and concept maps provide visual data about students' higher-level thinking (Novak 2003). The following assessment requires understanding of a number of concepts and promotes discussion within groups.

Application and analysis problem

Students examine the different types of genetically modified crops described in Marvier and Van Acker. They select one of the crops and fill in the box model below. In each box, they put the name of the organism at the top and the cellular component of the organism that is involved in transgene transfer at the bottom. They use arrows to connect the movement of the transgene from the organism in the laboratory to organisms in the field. The number of boxes depends on the number of transfers. Next to each arrow, students explain the

Panel 1. Assessment using canola as the crop

Students begin with a blank template. This sample box model was drawn using web-based C-TOOLS (http://ctools.msu.edu/); post-it notes or a box model template on paper also work.



processes that enabled the movement of the transgene and the expression of the trait. Students can also indicate possible places in the pathway where transgenes could escape and explain why this might happen (Panel 1).

Second step: instructors move from assessment to designing research on learning

What did students' responses to the concept questions and problem tell the instructor about their understanding? For example, did students understand the relationship between gene modification, movement, and expression, or the connection of genotype to phenotype? If not, what can an instructor do? One pathway is to investigate students' difficulties in understanding as a research problem, using the guidelines in Panel 2.

Panel 2. Guidelines for planning research in education

- What did the assessment data suggest about student understanding?
- Why didn't students understand critical concepts? This can lead to a researchable question worth pursuing.
- What has been done already about students' understanding of these concepts and does the research you have proposed have the potential to contribute to the knowledge base?
- How and why will you select the methods? Consider design research methods as a way to refine teaching practices (Collins *et al.* 2004; Suter and Frechtling 2000). Design research is used by engineers, computer scientists, and now educators.
- What kinds of data will you collect, direct (eg tests, reports, performance, observations, interviews) and/or self-report (eg surveys)?
- How will you analyze the data? Both descriptive and univariate statistics are useful tools. Also, extended response answers from students can be coded and counted, then statistics used, as shown in Ebert-May *et al.* (2003).
- How could the results influence instruction? Would you modify the instructional design, the assessment, the students' role, your role?
- Where should the study be reported? A summary of possible journals appears on the FIRST II website (www.first2.org).

Final note

This article is intentionally less prescriptive than our previous Pathways to Scientific Teaching papers. Our observations and those of others indicate that many faculty are implementing new teaching strategies in their courses, yet few are asking questions and systematically gathering data that have the potential to contribute to our understanding of how students learn (Shavelson and Towne 2003; D'Avanzo 2003). Ultimately, this type of research will contribute to the continuing improvement of undergraduate science instruction and catalyze further exploration into learning.

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