Bridging the pathway from instruction to research

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The Pathways articles to date were intended to engage faculty in teaching, learning, and assessment, especially in large enrollment courses. The challenge for many faculty who have changed their courses is to determine if the innovations actually improve student learning. This leads some faculty towards research models that require empirical evidence based on student assessment data.

Here we describe a framework for research on scientific teaching. Articles in subsequent months will provide practical advice for faculty who are interested in classroom research. We will use constructivist theories of how people learn (ie existing knowledge is used to build new knowledge; Bransford *et al.* 1999) to explore questions about how students actively gain meaningful understanding (Ausubel 2000). We also provide examples of research strategies and how one might gather evidence to assess changes in student learning.

Inquiry into students' learning

Recognizing a problem in student learning

To scientists who have committed their lives to education, research, and the pursuit of knowledge, it may take a great deal of self-reflection and bouts of frustration to arrive at the question, "Why aren't students learning in my course?" This is the first and most important step for catalyzing change.

Self-reflection

In order to understand the extent of the problem, instructors must look closely at individual student work and talk with students who show indications of low achievement in class. "What does student work tell you about their learning? What are your assumptions and the variables you need to recognize to effectively interpret student work?" Each teacher will have a different take on these questions and will approach the problem from a unique perspective. The direction taken will be a discovery process for newcomers to this type of inquiry, and questions of confidence may arise as instructors go beyond their comfort zone of disciplinary expertise. Perhaps you recognize yourself in the statement, "I was not formally trained to do this. I don't know anything about educational research".

At this point it may be helpful to think about your interest in and reasons for pursuing inquiry into learning. How much time, energy, and support do you have to commit to classroom research? What are your goals? Is the inquiry purely for yourself and your students' benefit? Or do you plan to share your investigation with others? Perhaps you are in a position where you need to convince others about the value of your instructional strategies, course, curriculum, or program. At what stage are you in your career? Is teaching excellence recognized as the basis for promotion and tenure? From a practical point of view, Kreber (2002) provides helpful descriptions of teacher development along a continuum of inquiry into learning, starting with the *effective* or *excellent teacher*, and *expert teacher*, to those who fully engage as *teaching scholars*. Through self-reflection, energy and time, effective or excellent teachers provide the most stimulating and inspiring learning environment possible, convey concepts in an active way, and help students overcome difficulty in their learning. The expert goes an additional step, consulting literature on pedagogy, attending workshops, and entering into a discourse with colleagues about teaching and learning. Research on teaching and learning starts with self-reflection and conversations with colleagues. A growing number of educators are going even further to pursue scholarship in their teaching, seeking ways to publish their work in a peer reviewed setting. Most importantly, instructors must remind themselves explicitly that one does not have to be a teaching scholar to help students learn.

Diving deeper, doing research

As teachers undergo systematic study of their own practice and student learning, they develop greater insight into potential problems. Undoubtedly, many of the issues that arise are connected with motivating students to think critically and inspiring them to take ownership and initiative for their own learning.

Using an example from this issue of *Frontiers* (Walters *et al.* pp 75–79), we outline a general framework for moving beyond instruction to investigating a research question. In this case, we examine students' ability to demonstrate critical thinking about ill-structured problems (ie those that cannot be described with a high degree of completeness or solved with a high degree of certainty; eg overpopulation), in contrast to well-structured problems, (ie those with a high degree of completeness, certainty, and correctness; eg a puzzle; King and Kitchner 1994). We designed an ill-structured problem (Panel 1) that integrates several ecological topics, including invasion biology, weed ecology, biodiversity, community dynamics, and population growth, as a starting point to discuss a research approach

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Panel 1. Example problem about invasive species *(species and biology are accurate; the situation is hypothetical)*

San Diego Daily News

The green creep: killer algae

An environmental monitoring team associated with Southern California Caulerpa Action Team plans to release thousands of non-native tropical sea slugs (*Elysia subornata*; Mollusca) into a coastal lagoon in Southern California over the next two summers, in an effort to control the spread of an invasive green algae (*Caulerpa taxifolia*). This plant, dubbed "killer algae" by European scientists following Alexandre Meinesz's 1999 book by the same name, spreads "like cancer" and is difficult to control, given its broad environmental tolerance and few predators. The monitoring team has tried covering *Caulerpa* stands with tarps and then applying chlorine underneath the covering. They plan to test the effectiveness of the sea slugs as a biological control for the *Caulerpa*. This project follows previous laboratory and field studies with sea slugs in experimental pools, which resulted in successful eradication of *C taxifolia*. If the sea slugs fail, this invasive alga will pose a substantial threat to marine ecosystems in California, particularly to the extensive eelgrass meadows and other benthic environments that make coastal waters a rich and productive environment. Is release of *E subornata* into California coastal waters a reasonable and promising plan for control of *Caulerpa*?

Questions to consider:

- The words "invasive species" are in the news all the time. How do we know, and what is the evidence, that this species of alga is invasive?
- What is the basis for the threat of *C taxifolia* on California's marine ecosystems?
- What are the risks and benefits for release of *E subornata* into the coastal lagoon?
- What are the alternatives for controlling the spread of *Caulerpa*? Are these reasonable, good alternatives?
- On what basis would the research team make their decision about the effectiveness of *E subornata* as a biological control agent?
- What information do you need and what basic assumptions would you consider to estimate the impact of releasing *E subornata* into this coastal lagoon?

to analyze students' critical thinking. The learning objectives and instructor's research goals provided below are general enough to be customized to different courses.

Learning objectives for critical thinking

Students should be able to:

- Generate questions and identify important variables and assumptions associated with an ill-structured problem.
- Gather information and data from the literature to help generate a logical argument and inform decisions.
- Describe and explain limits of an argument based on assumptions and analysis of the strength of evidence, and present potential consequences and alternative solutions.
- Construct a model or design an experiment that informs decision making for solving a complex problem.

Research goals

- Use pre-test data to pose a specific question about student critical thinking that can be investigated empirically (see March 2005 Pathways article for types of questions).
- Use a rubric designed to evaluate aspects of critical thinking revealed in student work.
- Develop a coding scheme to categorize student responses within the context of the rubric and to help generate evidence to explain student reasoning.
- Combine quantitative and qualitative student data to draw conclusions about the effectiveness of an instructional strategy to promote student critical thinking.

Process of inquiry into student learning

Before presenting students with the ill-structured problem, instructors should consider developing a pre-test to reveal preconceptions and identify learning issues or potential difficulties. Pre-tests can be developed to uncover misconceptions in multiple-choice format, using alternative concepts as strong distracters. Alternatively, short answer responses may provide information to help define the level of expectations for the assignment and to gauge the instructional pace and how to stage the activity.

Example pre-test

1. What characteristic(s) do you think make a species invasive?
2. What characteristic(s) do you think make a habitat susceptible to invasion by a non-native species?
3. Name an example of an invasive species that you know of and explain:
   - What characteristics have allowed it to invade habitats easily?
   - What are the consequences of invasion?

Implementing classroom instruction

Instructors could stage an activity based on an ill-structured problem (Panel 1) by directing students to form smaller groups through informal "turn-to-your-neighbor" clusters or use of established groups. The instructor may choose to give students some background information in the form of homework reading or mini-lectures, or have them find information entirely on their own. The activity should prompt initial questions that serve as a springboard for further investigation. The method by which students get their information in a more or less guided way is important when considering the level of student investment and ownership in their argument and proposed solution. By facilitating greater student autonomy in the classroom, instructors shift the spotlight off of themselves, helping to create a student-centered rather than instructor-centered classroom (Finkel and Monk 1983).

Evaluating student work

Instructors should design assignments that allow students to

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Panel 2. Example rubric

Excerpt from Facione and Facione (1994) developed through iterative testing and validation. Criteria at each level explicitly define instructor expectations associated with critical thinking evident in student responses. Two of the four levels are described as follows:

Level 4 defines student responses that:

"Consistently do all or almost all of the following: accurately interprets evidence, statements, graphics, questions. Identifies the salient arguments (reasons and claims) pro and con. Thoughtfully analyzes and evaluates major alternative points of view. Draws warranted, judicious, non-fallacious conclusions. Justifies key results and procedures, explains assumptions and reasons. Fair-mindedly follows where evidence and reasons lead."

Level 1 defines student responses that:

"Consistently do all or almost all of the following: offers biased interpretations of evidence, statements, graphics, questions, information, or the points of views of others. Fails to identify or hastily dismisses strong, relevant counter-arguments. Ignores or superficially evaluates obvious alternative points of view. Argues, using fallacious or irrelevant reasons and unwarranted claims. Does not justify results or procedures, nor explain reasons. Regardless of the evidence or reasons, maintains or defends views based on self-interest or preconceptions. Exhibits close-mindedness or hostility to reason."

articulate their understanding of the problem, the variables involved, and potential solutions. The final product may be in the form of an individual or group paper, poster, oral presentation, or public debate. Regardless of the format, the assignment should require that students prepare a document that allows examination of their argument, rationale, and logic. When it comes to evaluating student work, particularly written work that is difficult to assess with an entirely objective eye, rubrics are an essential evaluation tool.

Rubrics define instructor's expectations and criteria explicitly for each level of achievement. There are many rubrics available, as well as tools to help instructors make their own (Ebert-May 1999; Taggart *et al.* 2001). Often used solely for grading, rubrics are equally useful for initial evaluation of student responses in answer to a research question. Once expectations are defined in the rubric, the instructor should share it with the students, as part of the assignment. As an example (Panel 2), an excerpt from a general rubric developed by Facione and Facione (1994) may be particularly useful to help guide evaluation of critical thinking.

As roles change from instructor to researcher, it is important to calibrate the rubric, based on the learning goals for the specific problem. The process of developing a rubric for research purposes is iterative – initial criteria are defined and, with further use, refined so that student achievement levels are clear to all evaluators. Once researchers have categorized student responses using a rubric, they can look closely within categories to classify elements of the argument or reasoning and identify patterns of student thinking.

Classifying student use of particular words or phrases, assumptions and alternative explanations often leads to further inquiry by the researcher. Questions may include why students responded the way they did and if the response is cognitively relevant or an artifact of an ambiguous problem or instructional design. These types of questions are fuel for further investigations that may include surveys, interviews, and student self-reflection.

Final note

As faculty apply scientific curiosity, creativity, and reasoning skills in the classroom, they begin to pose questions such as:

- Are students achieving content objectives as well as developing higher-level thinking skills?
- Are students becoming more sophisticated in their ability to develop solutions to ill-structured problems?

Scholarly investigations about teaching and learning will contribute toward achieving excellence in undergraduate science education. When scientists critically examine and report their students' accomplishments in response to their instructional innovations, our understanding of "what works" in our courses will expand and catalyze further investigations. Ultimately, we encourage instructors to make their teaching and inquiry into students' learning visible to their colleagues and the public.

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