Diagnostic Question Clusters to Improve Student Reasoning and Understanding in General Biology Courses: Faculty Development Component

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Charlene D'Avanzo[1], Deb Morris[2], Andy Anderson[3], Alan Griffith[4], Kathy Williams[5], and Nancy Stamp[6]. 1. Hampshire College, 2. Jacksonville Community College, 3. Michigan State University, 4. Mary Washington University, 5. San Diego State University, 6. Binghamton University, SUNY, Binghamton, NY

Introduction

Since the last Conceptual Assessment in Biological Sciences meeting, we have received CCLI support for a program that targets two challenges to the teaching of General Biology: 1) Most students do not address biological questions with the principles and reasoning used by biologists and 2) Most faculty do not teach students how to use the principles and thinking of practicing biologists. To address these challenges, our proposal centered on a set of interrelated biological *Diagnostic Question Clusters* (*DQCs;* e.g. Wilson et al. 2006) designed to "hook" biology faculty to question and learn about their students' understanding of core biological concepts and ways of thinking about biology (see example below). As Andy Anderson, Joyce Parker, and John Merrill explained in CABS I (Anderson et al. 2007), one set of the *DQCs* they have developed concern tracing energy and matter through three levels of biological complexity (subcellular-organismal). In this new project we will expand this framework to a fourth level, ecosystem, and focus on this in our workshops for faculty.

Although the *DCQs* developed by Anderson et al. (2007) are based on extensive study and research, even the best diagnostic tools will not on their own lead to better biology instruction. College faculty need a great deal of help – using such tools, interpreting findings from them, and incorporating effective practices that help their students overcome common misconceptions and poor biological thinking. Therefore, in this project we are linking a set of well-researched diagnostic tools for teaching biology with a faculty development program. Specifically, we will study faculty use of *DQCs* developed to evaluate students' understanding of core biological ideas and ways of thinking. Faculty who teach General Biology in diverse institutions will use these *Question Clusters* as a means to improve their teaching via a faculty development program based on our experience with *TIEE* faculty development (see below) In this way, we will be able to study how faculty use such diagnostic tools in a range of classroom and institutional settings. Results from this study will help us understand whether diagnostics like the *Cluster Questions* are potentially effective tools for improving introductory biology teaching and learning - and the associated types of faculty development programs that we need.

Table 1. A question from our cluster on cellular respiration. Each foil represents a common incorrect response to open-ended questions and can be seen as indication of the problem as indicated in brackets**.** For example, when asked to trace matter, students commonly give an answer about energy. The correct answer is A, in bold. For more information about sets of *DQC*s, contact Andy Anderson (andya@msu.edu).

Jared, the Subway man, lost a lot of weight eating a low calorie diet. Where did all the fat / mass go? **A) The mass was released as CO_2 and H_2O.** B) The mass was converted to energy and used up. [*mass-energy conversion*] C) The mass was converted to ATP molecules. [*tracing matter]* D) The mass was broken down to amino acids and eliminated from the body. [*tracing matter*] E) The mass was converted to urine and feces and eliminated from the body. [*failure to move to cellular level*

Faculty resistance and reluctance to changing their teaching

Real change in basic biology teaching clearly necessitates faculty understanding how and why students so poorly understand important biological ideas and concepts. However, most faculty have limited formal knowledge about teaching and learning, and therefore engaging them in topics such as misconceptions and biological reasoning is a big step. How do we deal with this dilemma? What will entice faculty to take the time to become educated about problems so fundamental to teaching biology and ecology? To address this, we look to other faculty development programs that focus on science teaching and learning at the undergraduate level.

TIEE: Eight years ago, D'Avanzo et al. (2007) established *Teaching Issues and Experiments in Ecology (TIEE*), a peer reviewed publication of the Ecological Society of America (ESA) designed to help faculty include more student-active approaches in the courses, including lecture. A Research Practitioner program for faculty using *TIEE* is the basis for the new *DQC* project.

The *TIEE* Research Practitioners Project uses the concept of "action research," a mode of inquiry from education and related social sciences. Action research is done by practitioners (e.g. teachers) who ask questions and design studies that will directly inform their practice (Stenhouse 1975). It is different from evaluation in part because practitioners work in teams on common issues. Though done infrequently in higher education, college faculty have effectively used methods of action research to improve their own teaching even without grounding in the critical theory foundation of "pure" action research (Kember and McKay 1996; Webb 1996). Similarly, in *How People Learn,* Bransford et al. (1999) specifically recommend that teachers conduct research via formative assessment. Throughout that volume the importance of making students' thinking visible through frequent assessment, feedback, and revision, is emphasized, although the authors also acknowledges that " the knowledge base on how to do this effectively is still weak". Notably, these ideas are not new. John Dewey

75 years ago complained about the separation of education research and the disciplines being studied, saying that good teaching depends on "direct participation of those directly involved in the research" (Dewey 1929,47).

Interest and discussion of research on teaching conducted by college faculty themselves has greatly increased in recent years (e.g. NRC 2002, Fox and Hackerman 2003). Handelsman et al. (2004) use the term *scientific teaching* to describe teaching based on theories of teaching and learning and informed by empirical evidence. *Classroom assessment* (Angelo and Cross 1990) and *classroom research* (Cross and Steadman 1996) are increasingly popular ways for college faculty to engage in ongoing, practical inquiry into student learning. Clearly the terminology – evaluation, assessment, research, etc. - is confusing. We used the term "practitioner research" to describe inquiry conducted by faculty on their own practice, encompassing action research, classroom research, and scientific teaching.

In a 2005 summer *TIEE* Research Practitioner workshop, faculty formed self-selected groups based on common issues they wished to investigate in biology and ecology courses (D'Avanzo and Morris 2007). For instance, one team of four faculty from a range of institutions used pre- and post tests and other measures to study their students' progress working with data. In the two semesters after the workshop, faculty teams continued to work together via conference calls. During that academic year, these faculty carried out studies they designed in consultation with each other, collected and analyzed various types of data, pondered the meanings of their findings, and reworked their experimental designs. At the 2006 annual meeting of the Ecological Society of America, they presented six posters (several coauthored) describing their research and how the process of doing practitioner research was changing them as teachers. This led to eight publications in Vol. 5 of *TIEE* (refs). We consider this excellent progress.

In regard to faculty development, our major findings from this project are:

1. Importance of teams: Especially relevant to the new project is the finding that the team aspect of the RP program was essential. Faculty said that they likely would not have continued to 'stick it out' without the support and help of their team members. Several emphasized that, even though they had not participated in the conference calls and listserv discussions as often as they would have liked, just knowing that others were out there working on the same issues was motivating, plus they knew they could get help and support if needed.

2. Link between student-active approaches and aspects of scientific thinking: Also important is the deliberate link between use of a particular active approach (e.g. repeated group work with tables and figures) and gains in identified aspects of scientific reasoning (generalization from data in figures and tables to particular concepts or information). Faculty connected gains they measured in student learning with such focus and repetition.

3. Limited scope of study and iteration: A related point is that faculty limited their research to specific aspects of their teaching. They asked quite specific questions, developed ways to address these, examined their findings along the way, and used this feedback to modify their teaching over the semester. This is the essence of formative evaluation. However, our experience with *TIEE* is that most faculty do not engage in this practice, even when we specifically and repeatedly urged them to use the *TIEE* modules (D'Avanzo et al. 2005).

Lessons Learned From Other Science Faculty Development Programs

We are in the first stages of analyzing the literature on science faculty development programs and barriers to change in teaching for faculty (interestingly, these studies appear to be limited). From several relevant papers (Sunal 2001, Akerlind 2007, Dancy and Henderson 2007) key findings are:

Table 1. Key aspects of workshops and associated efforts to help college science faculty improve their teaching.

1. Interactions with other faculty are critical – faculty need to work with other teachers with similar teaching situations and whom they can trust; periodic interactions need to be scheduled ahead of time.
2. Action research is an important element for many faculty.
3. Programs should introduce faculty to education research.
4. Change begins with the goal to be accomplished, not the barriers.
5. Incremental change is the norm and a reasonable expectation.
6. Sophisticated teaching development means continually increasing one's understanding of what works and doesn't work for students.
7. Since teaching situations are very different, we need to provide easily modifiable materials.
8. Collegial and administrative support at the home institution is important.
9. Faculty should be seen as partners working with us on this program
10. We should acknowledge that change is difficult and support faculty, not criticize them.

Implications for our Biology Concepts Faculty Development Program

The specifics about how we will suggest that faculty use the *DQC*s in their biology course will take shape as we plan the 2008 summer workshop. So that we have common measures across institutions, we will likely ask that students be given a small set of diagnostic questions as pre and post tests in association with the ecology component of the course. Faculty will then decide now to use the rest of the DQCs and associated student-active (think-pair-share, concept mapping, jigsaw etc.) and formative evaluation approaches. The workshop will be designed to participants make these decisions to minimize on-the-fly decisions during the busy semester.

The findings outlined in Table 1 confirm our commitment to these aspects of our own program to help faculty use *DQC*s to improve their teaching of introductory biology:

- Faculty will work in teams most likely by institutional setting. Therefore workshop participants should include several faculty from R-1 universities, other universities, four year colleges, and community colleges. In addition, teams must continue to work together (e.g. via conference calls) over the academic year.
- Faculty should be introduced to numerous effective ways to do educational research in their courses (e.g. pre/post tests, surveys, extended response questions with associated rubrics).
- The Research Practitioner model (faculty doing action research on their teaching) is a good one. A related point is that faculty need advice developing strong education research designs.
- A critical component of the Research Practitioner model is scholarly publication of findings (posters, talks, papers). They will need help finding such venues.
- At the start faculty should focus their study on a limited aspect of the course (in our case on students' understanding of carbon and energy dynamics).
- Faculty need a range of options for using the materials (e.g. student-active approaches for large-small classes).
- In addition to the diagnostic tests themselves, and the associated framework, faculty need a variety of active teaching approaches specifically linked to the diagnostic material (e.g. how to use a multiple-choice 'clicker' question several ways in different settings)
- Follow-up workshops are critical

However, some of these recommendations seem at odds with the goals of national biology concepts inventories. For example, a very compelling component of the Force Concept Inventory studies is the large number of students taking the identical FCI test (Hake 1998). However, how do we encourage faculty to modify diagnostics for use in their courses and yet ask them to give students identical tests in the same way? We will continue to struggle with this question.

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