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Features

Approaches to Cell Biology Teaching: Mapping the Journey—Concept Maps as Signposts of Developing Knowledge Structures

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Strategies and associated philosophical underpinnings that fall under the rubric of "student-centered" or "inquiry-based" aim to help students develop the intellectual maturity needed to become independent, flexible, self-correcting learners able to make sophisticated analyses and reasoned decisions (McNeal and D'Avanzo, 1997). While the goals of student-active learning are relatively easy to articulate, the path toward their realization can be a "bumpy road" to navigate for both teacher and learner (Felder and Brent, 1996).

Not the least of the challenges to implementation of student-active instruction is that the requisite methods and structures ideally possess what Glaser and Baxter (in a paper presented at the National Academy of Sciences; cited by Ruiz-Primo *et al.*, 2001) define as "low-directedness." That is, to a large extent, students determine the procedures (the methods used have an open process), and a high conceptual knowledge demand is placed on them (the methods used are content rich). To students whose prior educational landscapes were dominated by high-directedness or instructor-centered terrains, a first encounter with active learning might seem at best a bemusing puzzle and at worst an unfathomable upset to their educational applecart. ("If you know the answer, why don't you just tell us? How am I supposed to know what to do?") An instructor contemplating a course transformation to incorporate a student-centered learning environment may feel faced with what seems like a high-wire balancing act—a constantly renegotiated compromise between students' legitimate needs for structure, well-understood expectations, and good grades and instructors' foreknowledge that the path to intellectual maturity is "in the doing," particularly if the "doing" presents a reasonable challenge (Vygotsky, 1978).

I (D.A.) was beginning to lose my balance on the high wire of active learning when I was fortunate to have the opportunity to represent my institution's fledgling problem-based learning (PBL) program at a National Science Foundation–sponsored conference on inquiry approaches to science teaching held at Hampshire College (McNeal and D'Avanzo, 1997). In PBL, complex, multifaceted dilemmas or situations initiate and compel students' learning of key concepts on a need-to-know basis (Allen and Tanner, 2003). My dilemma stemmed in part from the necessity to use the PBL method in one section of a multisectioned, introductory biology course with a common syllabus. Was there room for students to value forging their own path through the content-laden atmosphere of a good PBL problem, or would the specter of the "prescribed sequence of topics" outlined in the common syllabus undercut the value of all but the most direct path? In the face of the demands of prescribed content, would students perceive PBL as just an elaborate guessing game? And worse still, might they be right?

While I contemplated how best to tailor the PBL strategies to address this dilemma, some additional, more puzzling problems presented themselves as I reflected on my first attempts to teach introductory biology in this new way. Why had the students seemed so content to skim the surface of conceptual understanding in some key areas under the syllabus umbrella yet so eager to plumb other areas of biology, typically those outside the conventional content domain of the introductory course, to their deepest depths? Why, in the face of the personal autonomy, ability to explore answers to one's own questions, and reflective practice that a PBL learning environment could offer (Savery and Duffy, 1995), did some students still want to cling to the life raft of rote learning (of the steps of photosynthesis and the names of the phases of meiosis, for example) and fragmented knowledge? Why did they seem reluctant to test the waters of the deeper, more integrated understandings necessary for complex conceptual and procedural tasks?

These were some of the questions swirling through my head as I attended the above-mentioned conference on the theme of student-active science. An article by Joseph Novak

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(2003; "The Promise of New Ideas and New Technology for Improving Teaching and Learning") in Volume 2, Number 2, of this journal has provoked recollections of how that conference introduced me to the use of concept mapping. About midway through the conference, the co-organizers/leaders (Ann McNeal and Charlene D'Davanzo of Hampshire College) asked teams of participants to construct a concept map with the title "Reform in Undergraduate Science Education" and to be ready to display their maps to the room in 45 min. In doing so, the organizers put me neatly into the environment I may have inadvertently created for my students in my early attempts to use PBL. Although concept mapping techniques had been described and refined by Joseph Novak since the 1970s (Novak, 1976), they were completely new to me. I was immobilized as much by my uncertainty about what the "teachers" expected us to do as by a sense of the sheer enormity of the task. ("If you know the answer, why don't you just tell us? How am I supposed to know what to do?")

As the map swirled into shape around me, thanks to the combined efforts of the more informed science educators in my group, a thought also took shape—this could be at least a partial answer to the instructional dilemmas I faced. True to form for a naively enthusiastic teaching workshop participant, I returned from the conference determined to use concept mapping in the upcoming semester. I since have come to appreciate how the conference organizers/leaders saved me from a potential disaster by placing me in the role of cognitive apprentice—I got a striking sense of how my students might perceive their own introduction to concept mapping. In addition, the organizers demonstrated a use of mapping techniques that was consistent with both the PBL setting and my instructional goals: as a collaborative, informal, suggestive task—one aimed at providing feedback for growth in integrating new and existing understandings, in a context that acknowledged the community nature of knowledge construction. Unbeknownst to me, by simply mimicking the techniques I absorbed at the conference, I was actually on very solid instructional ground.

THE FUNDAMENTALS OF CONCEPT MAPPING

Concept mapping is a type of structured graphic display of an individual's conceptual scheme within a well-circumscribed domain (Angelo and Cross, 1993; Ruiz-Primo *et al.*, 2001). Although there are numerous permutations of operationally defined steps that can be used to construct a map, most methods go something like this (White, 2002):

Step 1. *Brainstorming stage.* Select an important or the most important concept within the map domain to serve as a stimulus or starting point. Identify all other words (nouns) that represent key concepts related to the map domain.

Step 2. *Organizing stage.* Establish a hierarchical ordering of the words (from most to least general or important).

Step 3. *Layout stage.* Begin to sketch out the map. The concepts (nodes) can be drawn within boxes or circles. The hierarchical ordering in Step 2 can then take shape as an arrangement of the nodes in a conventional top-to-bottom configuration or any other configuration in which the ordering can be readily perceived (a concentrically arrayed, in-to-out, or wheel and spokes configuration, for example). Cluster closely related concepts near one another. Figure 1 illustrates the beginnings of such a scheme as it could take shape for the map domain "photosynthesis" or at a deeper layer of a map of "cellular energy transformations."

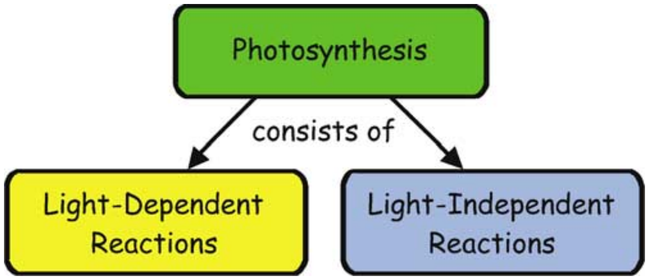

Figure 1. A small portion of a concept map that illustrates the basics of map construction. Concepts in boxes are arranged in a simple hierarchical scheme and are linked by a propositional phrase that describes one aspect of the relationship between them. More fully conceptualized maps are presented in a recent essay by Joseph Novak (2003) in this journal and can be viewed at http://www.cellbioed.org/articles/vol2no2/article.cfm?articleID=59.

Steps 1–3 can take the form of the ordered list and sketch as described above or the concepts can be written on Post-It notes or index cards that can be arrayed on any convenient surface.

Step 4. *Linking stage.* Establish *propositional linkages* between concepts. Propositional linkages are lines and words drawn between concepts that the map maker thinks are connected in some important way. Write the word or phrase (usually an adverb or verb) above each line that describes the essential connection between the concepts. For complex maps, also establish cross-links. These are similar to propositional linkages but are used to convey connections between concepts in different map areas, rather than between immediately adjacent ones.

Maps can be considered complete at this stage or can be refined and redrawn in final form.

CONCEPT MAPPING AS A SOLUTION TO INSTRUCTIONAL DILEMMAS: STRATEGIES AND LESSONS LEARNED

How did concept mapping eventually play out in the aforementioned introductory biology course that uses PBL strategies? I use mapping techniques two or three times a semester, generally midway through problems that are structured to begin with analysis of a situation requiring integration of ideas across several topical themes; we conclude using these conceptual understandings as "deep background" to inform resolution of complex issues. For example, in the "Who Owns the Geritol Solution" problem outlined in the essay on PBL in Volume 2, Number 2, of this journal (Allen and Tanner, 2003), concept maps help students frame the connections between cellular energy transformations and global biogeochemical cycles that lead to deeper understanding of how the Geritol Solution works (prior to formulating a decision about whether it should be used and by whom).

At the Student Active Science conference that first introduced me to concept mapping, the organizers made the reasonable assumption that many participants knew what concept maps are. I cannot make this assumption for the majority of the students in my courses (most have never seen a concept map), so I give them a handout on the basic steps for construction, along with a sample map with a conceptual theme previously encountered in the course. For nonmajors in a general education course, I ask them first to construct a map in a readily familiar domain outside the realm of biology (the campus food service, for example) if they seem hesitant about how to start the biology-related map. These instructions are enough to get students initiated into the mapping process yet are not intrusive and do not short-cut the creativity and thoughtfulness needed to construct a map de novo on a major topical theme. Concept mapping differs enough from textbook diagrams and other strategies for representation of key ideas that students are not able to fall back on memorization or (worse yet) simply copying from an existing diagram to complete their maps. (Again, kudos to Ann McNeal and Charlene D'Avanzo for introducing me to the power of map titles that define complex domains within the learner's grasp.)

I distribute self-sticking easel sheets for map construction—students post these on the classroom walls so that the emerging maps are readily visible to all PBL group members. This also conveniently sets the stage to end a concept-mapping exercise with a "poster session" in which students can take a look at the other groups' completed maps. The poster-session activity works equally well if student groups have mapped the same domain or have mapped different domains that also fall under the problem's content umbrella.

A thoughtful student gave me the insights that led to one more permutation of how concept mapping unfolds in this PBL context—I let students know the title of the map that they will be asked to construct at least one class period in advance, so that more reflective students are not put at a disadvantage (participation-wise) by "brainstormers," who tend to leap immediately to Step 3 of the basic construction scheme outlined above. While this allows students to prepare for the map construction activity independently, the maps are actually constructed by student groups. This practice not only reinforces course objectives related to understanding the nature of science (knowledge construction in communities of peers), but also results in more complex and sophisticated maps (Brown, 2003).

Because the issue of grading never came up at the conference, my grading scheme was not well thought out in advance of implementation. Again, this turned out to be a fortuitous mistake. Upon first witnessing how concept mapping enfolds in this classroom context, I immediately came to realize that using maps in a summative (final, formal, judgmental) assessment mode subverts many of the positive messages that the mapping activity can convey to students. First and foremost of these is that PBL is more about many possible resolutions supported by evidence and well-reasoned arguments, and the quality of assumptions and strategies on the path to one possible resolution, than it is about the single path (the one the instructor uses) to the one right answer (the one the instructor knows). I instead use maps as a way for students to reflect on their own knowledge structures and to inform my subsequent instructional choices. Students are given general criteria for a well-constructed map (for example, appropriate concepts, accurate and complete linkages, evidence of some hierarchical organization, evenness of coverage in different map areas when possible). I provide ongoing feedback to groups who stray too far from this ideal; a common example is groups whose maps are taking on a linear rather than branched structure. Students seem to more readily "buy in" to the idea that the map should represent their current thinking in this domain of biology when maps themselves are not formally graded. I do give students "participation points" for a serious effort at constructing the maps, and provide informal feedback to individual groups and the class as a whole about map conceptualizations that do not align with my own concepts or those of other experts. This nongrading approach also spared me from one of the most difficult aspects of implementing concept mapping in a classroom—trying to correlate the various permutations of accuracy and complexity possible for an expert in the field with a reasonable score for a student-generated map (Zelig, n.d.).

Surprisingly, despite this low-stakes, seemingly low-incentive grading scheme, no student group (in several course settings over 6–7 years) has failed to make a serious effort. While some are initially reluctant to get started (much like me with my first map), typically within about 5 min they get drawn into the process with all the rest. The classroom soon is abuzz with lively conversations, flying Post-Its, and even heated discussions—about the course content, no less. The take-home message—"It's in the doing"—rules the day.

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