Getting serious about science education

BY MIKE KLYMKOWSKY

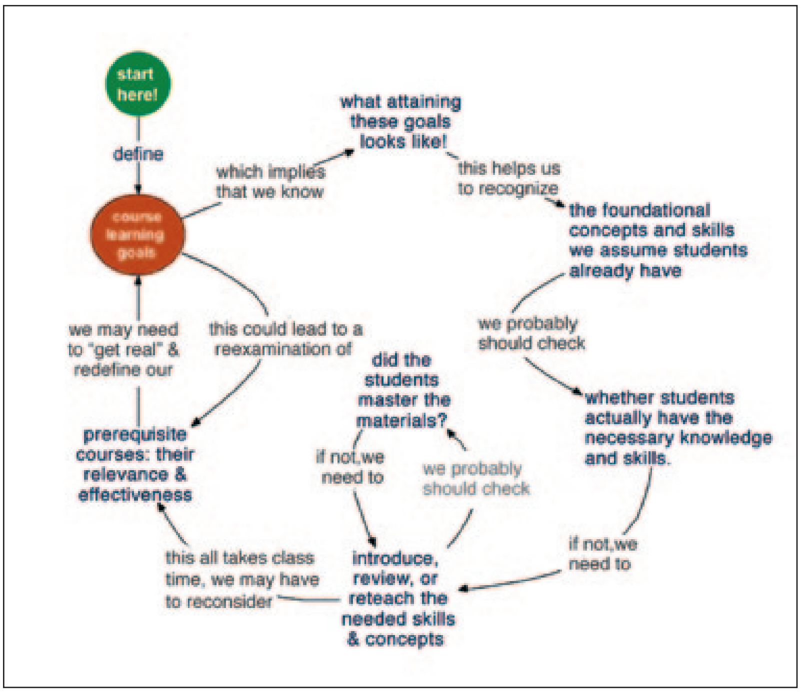
You may have noticed that the state of science education has been very much in the news of late, including reports from the National Academies (1) and editorials and articles in Science, the New York Times and the Wall Street Journal (2 – 4). Responses to the perceived problems in science, technology, engineering and mathematics education include calls for revised MCAT and College Advanced Placement exams, better science and mathematics standards (frameworks), and the appointment of prominent scientists, focused on education, to positions high in the government. While much of this activity has been centered on K-12 education, its impact can also be felt in higher education, where there is now greater emphasis on active engagement versus passive lecturing (5).

The problem

You might well ask yourself what drew so much attention to this subject — what is the evidence that our educational system is doing a bad job, that it needs reform? Early hints came from the work of Treagust and Hestenes and colleagues, together with an awareness that grades and conceptual understanding are not always correlated (6). One also can do one's own experiments — ask students or colleagues to describe the evidence that respiration and photosynthesis share a common evolutionary origin, explain why oil and water do not mix, describe the mechanisms by which mutations lead to novel phenotypes or consider whether DNA is inherently more or less stable than protein. The answers, or more often the hemming and hawing, might surprise you.

The recent emphasis on the science education system is based in large part on the perceived need to broaden the appeal of science and deepen appreciation for the scientific approach's value when thinking about a wide range of phenomena. While the current system is demonstrably adequate for those who succeed in it, it actively discourages the majority of students. All too often, the function of a science or math course is perceived by students (and, sadly, by some faculty) as a sorting mechanism rather than an opportunity to learn (and teach). This is a perception that can lead to the loss of important contributions and talent as well as misunderstanding of and hostility toward science within the broader community.

Recently, there have been a number of encouraging developments. For example, there is an increased emphasis on learning goals for science courses and curricula, although how far this has moved into the consciousness of most science educators is unclear. While learning goals are critical for effective instruction, they are essentially meaningless without a close link to informative assessment. Accreditation bodies, who you might think would be interested in the assessment of learning, only rarely require this type of data. Goals and assessments form complementary parts of a dialectic. The assessments needed are quite different from typical course exams (and assessments that correlate with exams are more or less superfluous). The types of assessments needed are those designed to reveal whether particular goals are realistic, whether they are being met, and if not, what is going wrong — they need to map



out how students are thinking about a particular idea.

In this light, it is critical that when a learning goal is formulated it is also illustrated: What exactly does it mean to achieve that goal? What kinds of questions should students be able to answer, and what should their answers contain? Such assessments dig deeper than the typical exam for a number of reasons (6, 7) and serve to provide feedback on the learning goals themselves as well as the pedagogical strategies used to attain them. Often authentic assessments (like Socratic dialogues) are uncomfortable for both the student and the instructor, since they are designed to reveal the limits of understanding rather than to identify who is paying attention. A simple strategy, applied to a multiple-choice question, is to ask students to explain why incorrect choices are wrong. This forces students to become explicit (and instructors to hear) about their understanding of both the question and the proffered response. When carried out rigorously, this dialectic between goals and assessments often reveals that apparently simple goals are quite complex and that students may not be prepared, either by curricular prerequisites or by their current instructional experiences, to address them. It also can reveal serious holes in students' understanding and, by implication, holes in course and curricular design.

A solution

Addressing such problems is not for the faint of heart and depends critically on the culture of the department and institution in which one finds oneself (as well as one's position in the hierarchy). Perhaps counterintuitively, a rigorous learning-goal analysis can lead to what appears to be a simplification of the materials presented, with the goal of producing a deeper, more rigorous and more confident understanding of key ideas. Consider, for example, gene expression. A thorough understanding of this process includes the thermodynamic factors involved in protein-protein and protein-nucleic acid interactions, the general effects of post-transcriptional and post-translational modifications, the stochastic and cooperative nature of the interactions that regulate transcription, RNA processing, transport, translation, the localization of gene products, the assembly of macromolecular complexes, the turn-over of RNAs, polypeptides and proteins, the repair of DNA and the geometric factors that regulate DNA's accessibility (epigenetics). From this perspective, for example, what is important about miRNA activity is not the details of miRNA processing but the fact that miRNAs (primarily) regulate mRNA stability and translation, a role (and in fact a mechanism) not conceptually distinct from that played by various proteins (a similarity rarely appreciated by students). A rigorous and confident understanding of the molecular underpinnings of gene expression prepares the student to approach more complex issues, such as making informed predictions about the effects of mutations and the behavior of the regulatory networks involved in adaptation, homeostasis and a wide range of processes from embryonic development to immune and nervous system function. But how many programs prepare students to even consider the noise inherent in gene expression and molecular behavior? And how many students howl in disbelief (or even recognize the error) when biological processes are displayed as deterministic, as is often the case, for example, in video presentations of various polymerization processes?

So how do we take science education seriously? I suggest that, just as in a scientific experiment, we must establish objective and informative assays and use the results of those assessments to provide feedback that serves to develop, constrain and redirect our learning goals. This is a contagious behavior, since it tends to infect other courses both within and beyond a particular department. If the learning goals in the biological sciences demand and depend upon an understanding of molecular-level phenomena, then we are within our rights to demand that the mathematics, physics and chemistry courses we require our students to take address these concepts. Within a departmental context, it is critical to present this type of analysis not as a critique of current teaching but as an opportunity to think seriously about the educational system in a scientific (that is, skeptical) manner. Effective change is likely to be evolutionary, not revolutionary; it will take a number of cycles of reflection based on informative assessment to achieve and continuing assessment to maintain a rigorous, welcoming and effective science education system. To paraphrase Socrates, perhaps we can come to appreciate that the unexamined course is not worth sitting through.

Mike Klymkowsky (michael.klymkowsky@colorado.edu) is a professor of molecular, cellular and developmental biology and co-director of CU Teach at the University of Colorado, Boulder.

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