Near Real-Time Assessment of Student Learning and Understanding in Biology Courses

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Computer technologies have transformed biology research, but the application of instructional technology tools to better connect teaching with learning has proceeded at a far slower pace. Especially in large-enrollment classes where many undergraduates are first introduced to biology, faculty can use computer-assisted instructional technologies to help gauge student understanding (and misunderstanding) of core science concepts and to better evaluate their own teaching practices. In this article, I report on two instructional technology tools, which prompt students to reflect on their learning and allow faculty to gauge student understanding of material almost simultaneously: (1) off-the-shelf personal response systems, modified for in-class assessment in introductory biology classes, and (2) a custom-designed Web-based assessment for use between lectures (BioBytes). On the whole, both faculty and students reported that these technologies helped to improve students' overall understanding of biological principles and concepts.

Keywords: instructional technology, assessment, innovative teaching, large-enrollment courses, computers in biology

Recent technological advances have changed the ways in which scientists conduct research and communicate their results, opening up entirely new lines of investigation (e.g., bioinformatics, ecological forecasting). Indeed, supercomputing tools allow researchers to construct and manage highly complex data sets (e.g., GenBank), testing hypotheses in ways that they could not have imagined 25 years ago. Clearly, biologists' lives and professional cultures have been profoundly affected by these technologies. Why, then, has this technological revolution not transformed courses and classrooms as well? How can computer-based technologies help instructors better connect their teaching with student learning? What types of pedagogical tools based on computer technologies can engage students as active participants in their learning?

New technology-based learning is consistent with the trend toward learning that is multisensory, interactive, and experiential, all of which are important elements in deeper-order learning, understanding, and knowledge (NRC 2000). In addition, using computers to integrate students' opportunities to interact with course material tends to change the typically competitive course dynamic to one that is more collaborative (Starr 1996), more student centered, and more focused on students' cognitive development (Brewer 2003). An additional benefit of integrating computers into instruction is that they may help level the playing field for students from groups that are underrepresented in science (NRC 2000).

Although faculty generally acknowledge that computers have instructional value in engaging student learning, the results of a campus-wide survey I conducted at the University of Montana (UM) in 2002 indicate that faculty are adopting computer technology into their teaching at vastly different rates. By and large, faculty reported using computer-aided instruction (CAI) mainly for applications related to course administration (e.g., posting course syllabi, listing assignments, posting additional Web links) and not for activities that promoted interaction among students or further engaged students with the course material. These results are consistent with those from other studies (Mitra et al. 1999, Butler and Sellbom 2002) and suggest that the real power of technology to enhance student learning is underutilized. For example, most of the 138 UM faculty who responded to the survey indicated that they use computer technology to extend traditional teaching methods (figure 1) and to post information on course Web sites (figure 2). However, fewer than 10 percent responded that they use CAI for promoting interactions among students or for formative assessment (assessment that is used to adapt teaching methods and provide feedback for students during a course) (figure 3).

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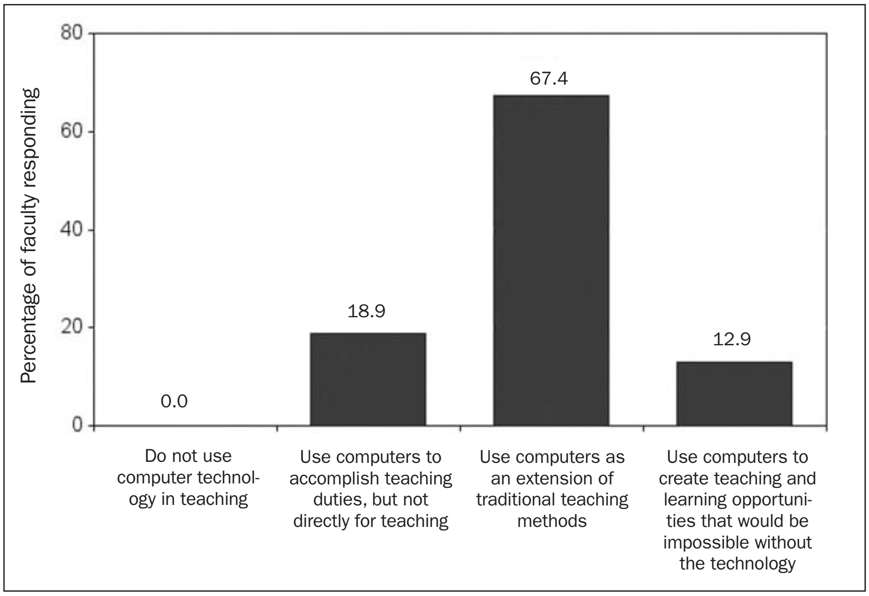


Figure 1. The degree to which faculty at the University of Montana (*n *= 138) use computer technology in their teaching, according to a 2002 survey.

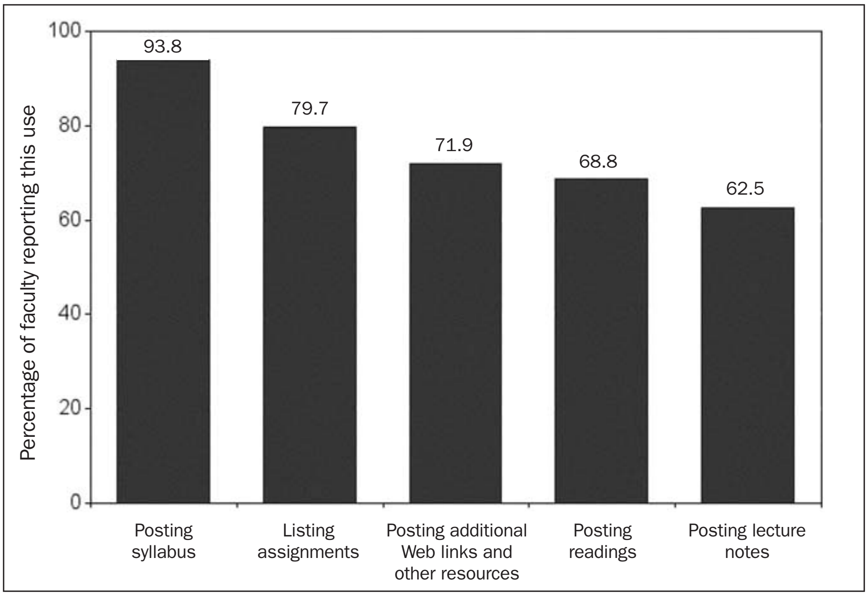


Figure 2. The five most common uses of a course Web site by faculty at the University of Montana (*n *= 138), all related to posting information online.

A major challenge for faculty is to develop courses that are more student centered and pedagogical strategies that better link thinking skills with conceptual understanding (Mentkowski et al. 2000). Furthermore, faculty need access to assessment and classroom research techniques that can help them better connect how they teach with what students learn (Angelo and Cross 1993). In particular, science faculty need technologies designed to help them gauge student understanding (and misunderstanding) of core science concepts in the large-enrollment classes where many undergraduates are first introduced to science (Ebert-May et al. 1997). Tools need to be designed to help faculty focus more on their own teaching practices (NRC 2001) and to overcome the commonly reported barriers to the use of CAI (e.g., insufficient knowledge of how technology can enhance learning beyond traditional methods, concerns about reliability, lack of incentives and administrative support; Brewer 2003).

Technological tools need to be more than mere extensions of lectures and text-based instruction. Strengthening the teaching and learning connection with CAI means more than transferring neatly typed overhead transparencies to PowerPoint slides, or having students look for information on the World Wide Web instead of working in the library. Rather, educators need to discover for themselves new ways to use technology to facilitate what they want to accomplish in the classroom. This means reorganizing teaching methods to focus on the student learning opportunities afforded by these rapidly evolving technologies.

From 1998 to 2003, with a grant to UM from the Howard Hughes Medical Institute, my colleagues and I applied, designed, developed, and tested a number of prototype CAI technologies intended to improve the teaching and learning of science in large-enrollment courses. These included more traditional Web-based, after-class discussions of course material; off-the-shelf technologies like the personal response system (PRS) software and hardware packages, adapted for real-time assessments in introductory biology courses; and an interactive, Web-based, near real-time assessment called "BioBytes" that we developed for use between lectures (*www.ibscore.org/faculty1.htm*). Both the PRS and BioBytes technologies are discussed below.

Transferring technology to the large-enrollment classroom

The UM biology faculty purchased and used PRS technology and the associated pedagogy described by Mazur (1997) to probe student understanding during lecture meetings. With the PRS, we could gather information to help make decisions about whether or not to move on to a new topic. We hoped to use this technology to focus on teaching and learning goals, and to conduct real-time or near real-time assessments that were practical and reflected actual learning experiences.

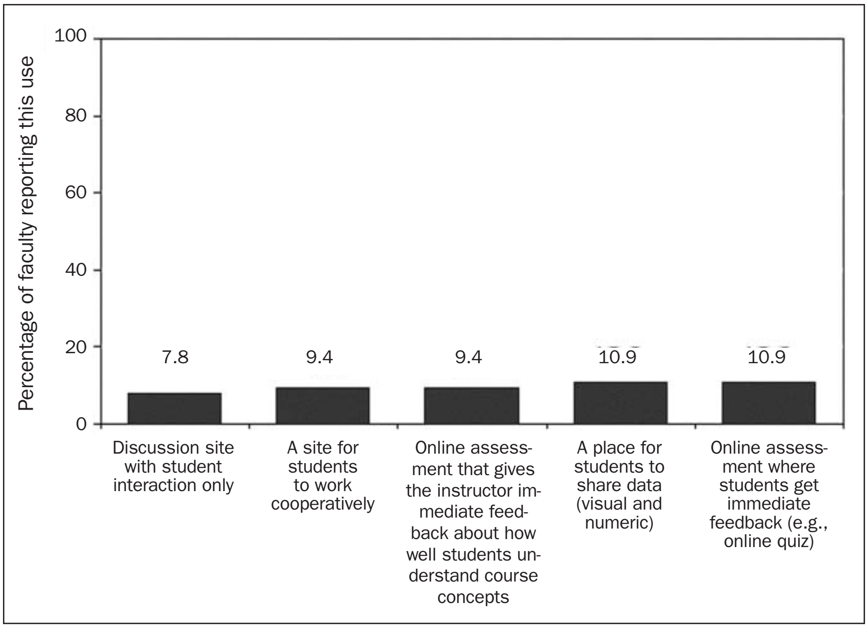


Figure 3. The five least common uses of a course Web site by faculty at the University of Montana (n = 138), all related to student and faculty interaction.

To use the PRS, we developed questions that required students to choose between the correct answer and incorrect responses that reflected different misconceptions students might have about the material. Students used the PRS transmitter to respond to each question and to rate their level of confidence in their answer. Within seconds, student answers and confidence levels were compiled, graphed, and projected onto a screen for review and discussion. Often students realized that the most frequently chosen answer was an incorrect one. As an immediate follow-up, students discussed the plausibility of each answer in small groups and then used the transmitters to answer the question again. As in the results described by Mazur (1997), the students' confidence levels in their answers tended to increase after they debated the answers in their small groups and addressed misconceptions with their peers. Typically, after one or two breakout discussions, more than 90 percent of the students chose the correct answer with high confidence. However, some students still held onto misconceptions even after extended discussions and lectures on a particular topic, indicating that additional attention to remediation (e.g., tutorials) might be still be necessary.

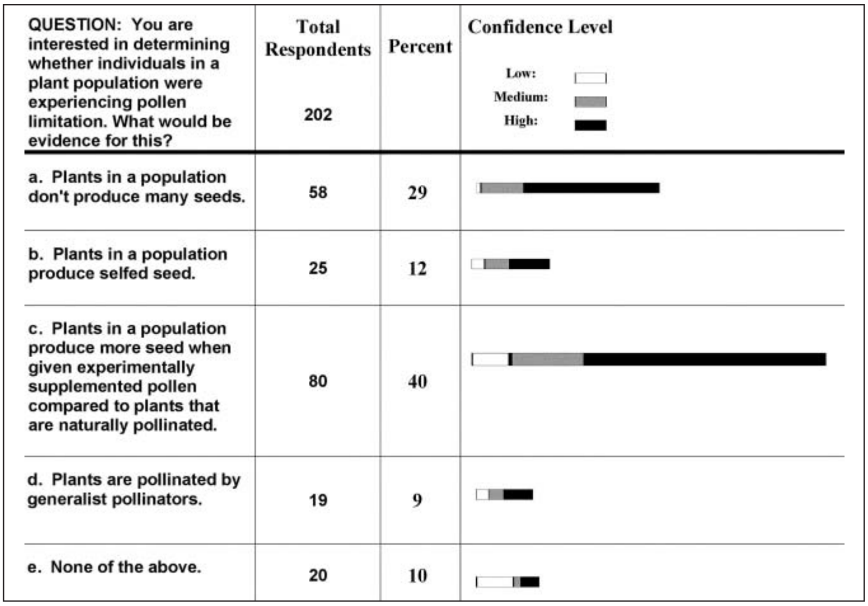
The benefits of PRS technology in this instructional setting were that instructors received additional quantitative feedback to help pace the course and that students had time to discuss and reflect on their understanding of the material, while calibrating their understanding of core concepts with that of other students. At UM, and at other campuses I have visited to discuss the challenges of teaching large-enrollment science courses, many faculty have expressed interest in using the PRS technology in ways that were similar to the ones described above; but because the system is expensive, it is not readily accessible to everyone who would like to implement it as an instructional tool. In addition, many faculty have expressed concern that using such a tool in their course would be too time consuming.

BioBytes: Learning science one byte at a time

Building on our experiences with the PRS, and on faculty concerns about using it in the classroom, we developed and tested BioBytes, a Web-based alternative to in-classroom, real-time assessments. This technology proved to be extremely popular with faculty and student users at UM, suggesting that it has great potential to improve both teaching and student learning of science. Our objectives for the software were (a) to provide faculty with an easy-to-use tool that would help them connect their teaching with student learning and make timely instructional decisions when there was still time for remediation before a high-stakes midterm exam, and (b) to offer students ample opportunities to reflect on their own learning and on their confidence in understanding the new material. The application of this technology actively engaged students between lectures outside the classroom by posing questions and problems and then instantly displaying compiled student responses (figure 4). This near real-time approach still allows faculty and students to reflect on student learning and to identify general misconceptions, yet it does not sacrifice classroom instructional time. The pedagogical goals for the tool were to (a) engage faculty in discussions of innovative teaching in large-enrollment lecture courses, (b) provide faculty with professional development related to asking questions (particularly for probing student misconceptions and gauging student understanding of concepts discussed in each lecture) and to pacing instruction in their courses, (c) foster out-of-class discussion and interaction among students, (d) stimulate students to wrestle with questions or problems before class meetings as preparation for specific lecture topics, (e) use response tallies as a basis for focused mini-discussions in class, and (f) give students practice with the types of questions they would see later on exams.

Using a Web-based assessment tool

The BioBytes software was tested by biology faculty at UM for five semesters in large-enrollment introductory biology courses. More than 1200 students used this tool regularly to gauge their learning in these courses. At least once per week, and sometimes after each lecture, faculty used the Web-based software to link questions about key concepts to their course Web page. Like the questions developed for use with the PRS, the Web-based questions were in a multiple-choice format and could accommodate a picture, graph, animation, or Web link. We did not use BioBytes as a quiz; instead, students were prompted to review the most significant elements of a



QUESTION: You are interested in determining whether individuals in a plant population were experiencing pollen limitation. What would be evidence for this?	Total Respondents 202	Percent	Confidence Level Low: ☐ Medium: ▨ High: ■
a. Plants in a population don't produce many seeds.	58	29	
b. Plants in a population produce selfed seed.	25	12	
c. Plants in a population produce more seed when given experimentally supplemented pollen compared to plants that are naturally pollinated.	80	40	
d. Plants are pollinated by generalist pollinators.	19	9	
e. None of the above.	20	10	

Figure 4. Example of BioBytes software output, including a restatement of the question, the number and percentage of students responding to the question, and the confidence level reported by the students for each possible answer.

particular class meeting by choosing what they considered to be the best answer to each question. Along with the answer, students rated their confidence (low, medium, or high) that the answer they had chosen was correct. After they submitted their answers, the results were tallied and graphed immediately for student viewing. The number of times an answer was chosen, the percentage of students choosing that answer, and a graph representing the confidence levels of respondents were displayed for each possible answer (figure 4). Correct answers were not provided to students until the next class meeting, an additional incentive to attend the lecture.

Because the graphical tallies of student responses were displayed instantaneously, the value of this information might be greater for students who answered later rather than earlier during the response period. Therefore, what happened during the class meeting after the between-lecture assessment was very important. Correct answers were verified at the beginning of the class session. At this time, the instructor could review the set of online questions, facilitate a discussion to address evident misconceptions in the student responses, or both. Moreover, because the confidence level would also indicate how well all the students *thought* they understood the material, the instructor would have substantial information with which to make decisions about the extent of instructional remediation that would be necessary before moving on to a more in-depth discussion of the current topic (or to an entirely new topic).

It is worth noting that this Web-based assessment tool is not simply an online quizzing system, but rather a near real-time formative assessment for faculty and students alike. An important distinction is that the software was designed to display class results and confidence levels in the answers provided. To choose a confidence level for their answers, students would need to reflect on their own thinking. Were they just guessing, did they have a few doubts, or were they quite sure that their response was correct? Furthermore, after they submitted their answers, students could review graphical data summarizing the responses and confidence levels of the other students, providing yet another opportunity to reflect on their answers. Were they right in line with what everyone else was thinking? Or did they have an unpopular response, but feel confident that their answer was correct? After using the Web-based assessment software on a regular basis, students quickly learned that a popular answer was not necessarily the correct one.

My colleagues and I used this technology to receive immediate feedback about how well *all* students understood the course concepts; thus, it was critical to us that as many students as possible participated. To provide incentives for involvement without the fear of the penalty of a poor grade for failing to answer a question correctly, we gave "participation credit" (e.g., five points per completed question set, totaling about 10 percent of the grade over the course of a semester) for responding to Web-based question sets. A database programmed as part of the BioBytes software automatically recorded participation when students logged in to answer questions.

Because students were given credit for their participation (and not for the correctness of their answers), there was a possibility that students might randomly choose answers without carefully considering the questions. If a large portion of the class did this, then the student response graphs would be skewed and less helpful in tracking student understanding of lecture material. Although some students in our introductory courses reported (on course evaluation surveys) that they knew of other students who randomly chose answers, it does not appear that random answers noticeably influenced the overall results for any particular set of questions we asked, judging by the consistency of correct student responses over several semesters of using the assessment tool.

Clearly, a tool like this could also be used to give graded quizzes. Using a Web-based assessment tool as part of a grading scheme could increase study time and reduce any inclination a student might have to guess or randomly select answers just to receive "free" points for participation. However, for the application described here, we decided to focus on using the tool to look for general understanding of concepts presented in class, and to allow students an opportunity to gauge their understanding without the higher-stakes pressure of a grade.

Reflecting on teaching and learning

Technology can help instructors improve their teaching in ways that extend beyond the direct benefits of the technology itself. Consider, for example, the kinds of multiple-choice questions that faculty tend to ask. During the first semester that BioBytes was used at UM, instructors tended to ask questions of factual recall almost exclusively. Consequently, we added a feature to help faculty reflect on the levels of student learning and understanding that their questions addressed. Prompting instructors to think about the types of question they used encouraged them to use a more balanced approach to asking questions. Now, when faculty use the BioBytes software to prepare Web-based question sets, they are asked to identify the type of question as *factual recall* (which emphasizes the process of remembering, memorizing, recognizing, or recalling the appropriate material), *conceptual understanding* (which requires the student to understand how sets of facts fit together), or *application* (which requires the student to analyze the material he or she has learned and apply it to a new problem that has not been discussed in class). As a result of this modification, faculty must reflect on what type of skills they are asking the student to use in order to respond to BioBytes questions. Note that if a particular application has been explicitly presented in a lecture or lab, a question based on that application may become a question of factual recall for that class. Of the instructors who responded to a questionnaire after using the software in the introductory biology series at UM, all either agreed ($n = 4$) or strongly agreed ($n = 4$) that this feature reminded them to ask a variety of question types.

Overall, the faculty who used this instructional technology reported satisfaction with the system. For example, all faculty responding to the questionnaire ($n = 8$) agreed or strongly agreed that "it was helpful to...receive feedback about what concepts students did not understand from the previous lecture." Both faculty and students were asked how often Web-based question sets should be used to prompt reflection on course material. All responding faculty recommended using the question sets after every lecture (figure 5), while more than 90 percent of students recommended using them at least once per week.

Students who regularly answered the Web-based question sets reported that they reflected on their learning more often over the course of a semester. For example, nearly 70 percent of the students surveyed in the UM introductory biology courses in 2002 and 2003 agreed "answering BioBytes made me think about course material outside of class" (table 1). According to one student, the regular assessments "help[ed] me by reinforcing the day's lecture and asking key points that clarify areas I probably had not connected"; in general, students reported that the system was valuable for studying for exams (table 1).

Summary and lessons learned

One of the goals of effective teaching should be to open the door of discovery to all students (NRC 1997). Now, more than ever before, instructional technology can broadly influence teaching methods by supporting the creation and mastery of knowledge (Dede 2000) and by providing new opportunities for interaction and collaboration between students and faculty. Integrating information technology into instruction can provide students with more experiences of how knowledge is discovered, created, shared, and shaped in their fields. Our experience shows that both students and faculty at UM believed these tools aided learning in their courses.

Why is instructional technology not being integrated more fully into classroom instruction, in ways that better connect teaching with student learning? According to Cuban (2001), most postsecondary educators with research responsibilities lack the time to become proficient in emerging technologies or to envision the potential of technology as a teaching tool. Many faculty have embraced information technology as a means to extend traditional lecture- and text-based education systems, but they often use this technology only to post syllabi and lecture notes on course Web sites, or to provide threaded discussions and chat rooms on course material (see, e.g., figures 1, 2, and 3; Collins 1998). While these applications of CAI are useful, they do not tap the real potential for using computers to revolutionize teaching and learning (NRC 2002a). Indeed, recent National Research Council reports (NRC 2002a, 2002b, 2002c) call for the creation of effective models, developed with full understanding of the principles of learning, to

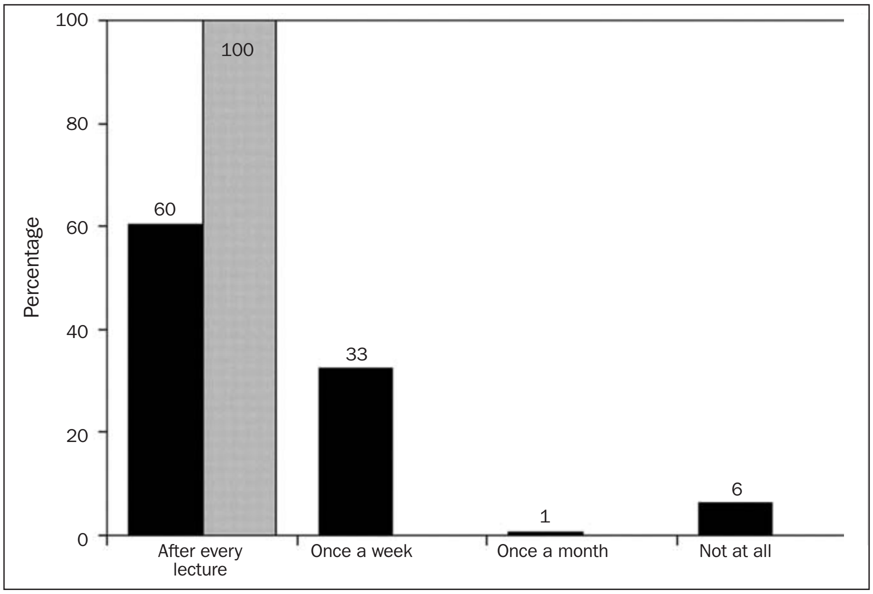


*Figure 5. Student (*n *= 280) and faculty (*n *= 8) perceptions of how often online questions should be used during a course to create an effective learning environment. Student responses are in black, faculty responses in gray.*

*Table 1. Responses by students in an introductory biology course (*n *= 270) to statements about using the online questioning system between lectures.*

Statement	Agree (percentage)	Neutral (percentage)	Disagree (percentage)
Answering BioBytes questions made me think about course material outside of class.	69	19	12
Online questions were good practice for the exams in this course.	71	19	11

promote interactions between technology, user-driven research, and classroom practice.

Effective use of information technology requires faculty to make decisions about course goals related to content, about what students should know and be able to do at the end of the course, and about how the learning environment (including the technological tools) will be organized to provide students with the best opportunity to meet the course goals and master the science (Brewer 2003). The power of a teaching tool lies in the pedagogy (Dede 2000), particularly if the tool has a low threshold for mastery, feels noninvasive to the instructor in the classroom, and promotes positive interactions between the instructor and students. These conditions can open the door to experimenting even more broadly with innovative pedagogy.

Using near real-time assessment technologies, such as the PRS and BioBytes software, provides an avenue for strengthening the teaching–learning connection, as evidenced in this study by improved student attitudes and self-reported increases in study time outside the classroom. Furthermore, our experience indicates that these technologies can be integrated into instruction with relative ease, allowing faculty to focus their teaching more closely on student learning, especially in large lecture courses. However, faculty need to develop more good examples of instructional uses of these technologies, especially in the large-enrollment classes where many undergraduates are first introduced to science. Additional work is needed to examine the impact of these types of technology on grades and other indices of student learning. Clearly, the instructional challenge in using any new technology is to find a balance between exposing students to course content and providing enough time for in-class discussion and student interaction.

In conclusion, CAI can have a transforming influence on science instruction by using nearly simultaneous feedback to link teaching more effectively with student learning. The extent to which instructors use technology to do this will always be a function of finding much-needed time. Moreover, whether or not faculty allocate their time to exploring and using CAI technologies depends on the incentives built into the reward systems on their campuses, and on the degree to which teaching and educational scholarship are valued in decisions about faculty retention and promotion.

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