Improving the Feedback Cycle to Improve Learning in Introductory Biology Using the Digital Dashboard

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Abstract: At Carnegie Mellon we are integrating timely and targeted feedback for the students and real-time student progress reports for the instructor to create an online learning environment that engages the student, improves learning and allows immediate adaptation of instruction. The Digital Dashboard is a dynamic portal into the continuous data provided by student use of online instructional tools and assessments within the Open Learning Initiative environment. The compiled data presentation from each lesson is a guide to changing and targeting instruction in the classroom. The Digital Dashboard organizes information and is being developed to link concepts, categorize answers to open-ended questions and provide a use-index to better inform the instructor of student learning. The information provides tools for making the classroom more dynamic and data for research on student learning.

There are many challenges involved in teaching introductory Biology courses effectively. Some of these stem from the fact that introductory courses generally have high enrollments, and others relate more specifically to the structure of knowledge in Biology. First, with high course enrollments, there is great variability in students' background knowledge, relevant skills, and future goals, which makes it difficult for the instructor to address students' diverse needs (Felder & Brent, 1996; Fink, 2003). Furthermore students arrive with preconceived views of the topics and a false sense of security in having heard many of the topics in previous courses. Second, the larger one's class, the harder (and more costly) it is to employ the best teaching practices that foster deep learning, e.g., personalized instruction, rich and timely feedback, and interactive learning environments (CFE, 2003; NRC, 2000). Third, even though the conceptual structure of knowledge in Biology is clear to experts, the array of new ideas and unfamiliar terminology in introductory courses tends to overwhelm students into memorizing a bunch of isolated facts (Chi, 2005; diSessa, 1993). Fourth, within Biology curricula, concepts are introduced initially in basic form and then applied and relied upon in multiple contexts, and yet students often compartmentalize what they learn, missing opportunities to connect their knowledge and generalize their understanding.

From research on how students learn, two well-supported principles have emerged that are particularly relevant to addressing these challenges. First, students' learning improves and their understanding deepens when they are given timely and targeted feedback on their work (Butler & Winne, 1995; Corbett & Anderson, 2001; NRC, 2000, 2001). By "feedback" we refer to corrections, suggestions, cues, and explanations that are tailored to the individual's current performance and that encourage revision and refinement. Second, for students to benefit from a conceptual framework that organizes the material they are learning, instruction needs to make that framework salient, and students need to practice making connections between related ideas (Eylon & Reif, 1984). A less studied area of research involves how instructors can best use information on their students' progress to effectively adapt their teaching. And yet, adapting instruction to students' needs is also consistent with the principle of student-centered teaching and hence should derive similar benefits (McKeachie, 2001; Slunt & Giancarlo, 2004).

This presentation will describe a set of tools designed to take advantage of these learning principles by improving the feedback cycle both for students and for instructors, in introductory Biology courses in particular and in other courses in general. The presentation will demonstrate innovative feedback techniques based on existing technologies that connect diverse data sources on students' work via an instructor's digital dashboard that facilitates meaningful display and interpretation of student progress in real time.

The Benefits of Feedback

The benefits of feedback have long been known (e.g., Thorndike, 1913), and yet recent research has greatly refined our understanding of when and how feedback should be given to best suit particular educational goals. Regarding timing and frequency of feedback, the best learning outcomes occur when feedback comes immediately after the students' response but not before the student is ready to make adjustments in his or her performance or understanding (Corbett & Anderson, 2001). Regarding the nature of feedback – as with instruction in general – it is more effective when presented in a way that relates to students' prior knowledge (NRC, 2000). Perhaps the most important finding regarding the effectiveness of feedback is that the feedback must lead students to revisit the activity that led to the feedback in the first place (Butler & Winne, 1995). Only then will the students get practice that exercises and extends their improved understanding. Together, these results lead to a model that explains why timely and targeted feedback is so helpful for learning. In essence, effective feedback (1) provides information targeted to the individual's recent responses and prior knowledge and (2) guides the student to refine his or her understanding through continued practice. A unique feature of our approach is that we also emphasize the role of feedback to the instructor. In this feedback cycle, the instructor gets information about students' current state of knowledge (e.g., common areas of strength or difficulty) and can refine his or her teaching to better address students' needs. In both cycles, feedback offers information – based on data gathered from students' learning experiences – that students and instructors can use to adjust their behavior. Examples of feedback to students include explanation of a misconception evidenced by the student's performance, cues to important conceptual relationships that the student missed, and suggestions to try a new exercise or a different strategy based on the prediction that it will aid the student's future learning. Examples of feedback to the instructor include summaries of class performance on particular activities or topics, catalog of identified areas of student difficulty, and reports on how far students have progressed through the instructional material. A guiding philosophy applies throughout the development of these tools and includes the following tenets:

- Develop flexible, modular, and modifiable tools and materials that instructors *can and will* use.
- Use technology judiciously but effectively.
- Bring together a multi-disciplinary team to address a common set of challenges and build a culture of educational research and development.
- Incorporate research from multiple literatures, including cognitive psychology, education, educational technology, and science education.
- Progressively refine our work based on formative assessment data.

The feedback tools discussed in this presentation form an important part of the course and its design. In particular, the design and implementation of the feedback tools is always conducted with a keen eye toward keeping students actively working with the material and offering frequent opportunities for self-assessment of their own learning progress. The instructional tools, some developed specifically for this context and others adapted to it, are all designed in light of best practices for teaching and learning. Finally, although the online course integrates these components into a coherent whole, we know different instructors will have differing needs. So, we make the components modular, adaptable, and usable in stand-alone form.

Putting it into Practice

The framework for this presentation is based on the collaborative development of an online Modern Biology course (www.cmu.edu/oli) with a team of domain experts, educational technologists and cognitive scientists. This work is funded by a grant from The William and Flora Hewlett Foundation. The theme of course development involves use of the best available research from the cognitive and learning sciences and continual evaluation and revision based on actual student-learning data. It is also important to note that, even though this is an online course for Modern Biology, its approach and many of the underlying concepts relate directly to Biochemistry and Chemistry courses as well. Hence, faculty from all three courses have been involved in the development of the online course, contributing their expertise both to help the online course and to inform the teaching and use of resources in their own courses. The online Biology course also represents a model of educational research and development – that of a multi-disciplinary team all focused on improving instruction. It has been through this project that we have come to appreciate even more the complementary areas of expertise that each member of the team brings to the table and to learn a great deal by working with each other. Development of the online Biology course involves creating instruction that goes far beyond a computerized textbook. For each module in the course, we create course content that interleaves text, graphics, animations, voice-over videos, simulators, interactive mini-tutors, comprehension and reflection questions, and more. From students' point of view, the pattern for each module is always one of reading the learning objectives for the given topic, gaining some initial exposure, and then continually learning and checking their understanding as they move through the online material (Brown, Bajzek, & Burnette, 2006).

The Tools Within the OLI Environment

Within the OLI environment there are many opportunities available for use by the instructor to assess student learning. In the online Biology course some of the instructional tools that provide feedback are:,

- *Interactive animations*: animations that allow students to visualize complicated biological processes and interact with the system by manipulating it. Self-assessment probes are woven throughout the animations.
- *Simulation environments*: Simulation environments offer the same features as the animations plus the opportunity to make connections among multiple, linked representations of key concepts. Embedded models allow the simulators to respond appropriately to student exploration.
- *"Did I get this?" low stakes quizzes*: No penalty quizzes following the presentation of concepts provide quick comprehension checks.
- *Embedded short essay questions*: Questions throughout the materials are designed to foster deeper reflection. These often require making connections between concepts and also may include requests for students' "muddiest points".
- *Mini-tutors*: A Mini-tutor is a learning activity that is one of the backbone tools of the OLI system. It provides very directed scaffolding and hints as well as immediate feedback to students as they work through steps of a problem. Mini-tutors are designed within the content as part of the learning of a new concept. They integrate the content on the page with a cognitive exercise.

The form of the feedback in each of these instructional tools is quite different for the student and instructor. For the student the feedback takes the form of guided instruction with pointers to reinvestigate a topic, fact or concept before progressing to the next stage of the inquiry, a set of hints to help reframe the question for the student, and matching of an open ended response with a model response provided only upon completing of the student's response. For the instructor, the feedback is provided both as individual student responses to open ended inquiries and graphic representations of performance on directed inquiries such as quizzes and tutors. This information is provided to the instructor as a link at the specific exercise in the course material. In addition the database of information from the interaction of the students with the material is also available for the instructor to address specific inquires about such issues as time on task, frequency of use, relationship of time of use to assessment execution.

Connecting diverse data sources on student progress and presenting them to the instructor via a *digital dashboard* that facilitates meaningful display and interpretation of the data.

As discussed above, a variety of new, feedback-rich instructional materials and tools are available within the online learning environment. Because these tools and materials are typically used by students through web interfaces, all of the students' learning activities with these tools are easily logged, stored, and then used for a number of purposes. One of these purposes is to provide the instructor with just-in-time data on individual and group learning so that misconceptions and errors can be corrected on a lecture-by-lecture basis rather than in a summative assessment after the fact.

Connecting these diverse data sources on students' learning is accomplished through an instructor's digital dashboard that coordinates, summarizes, and analyzes the data in order to give instructors an at-a-glance picture of their students' progress. The term "dashboard" is used to convey the idea of a tool that provides visibility to key indicators through simple visual graphics such as gauges, charts, and tables. Just as the dashboard in a car displays key information (e.g., current speed, cumulative miles covered, gas tank levels) that the driver needs in order to adjust his or her driving appropriately, an instructor's dashboard conveys key information on the moment-to-moment (and cumulative) state of his or her class in order to adjust his or her teaching accordingly. Table 1 presents a sample of the student-learning measures that will be input to the instructor's digital dashboard. The diversity and richness of these data highlight the unprecedented opportunity we have for keeping instructors in tune to the many aspects of students' learning. Note that these data sources may either be automatically transferred to the dashboard from stand-alone versions of our tools and materials, input from external sources (e.g., gradebook, course management systems), or directly linked via the integrated components of our online course. The design (and refinement based on use) of the instructor's digital dashboard presents this information in a concise view that is both easy to use and flexible enough to meet instructors' changing goals.

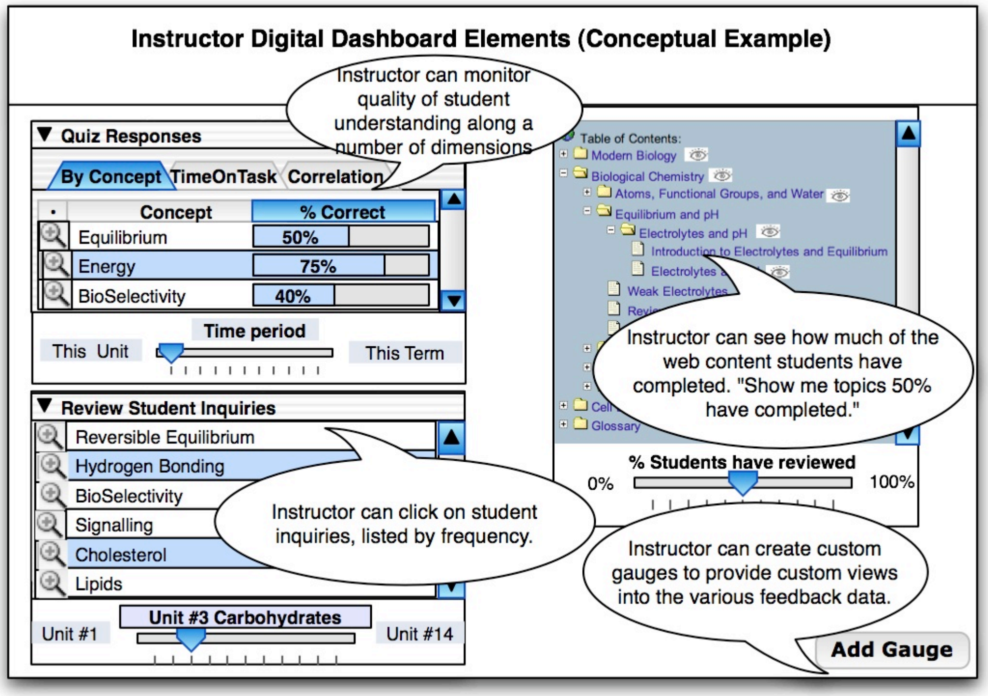

Table 1:
Sample student-learning measures culled from data

Assessment by concept: Calculation of % correct on particular concepts. With quiz items indexed by concept tested, taken from quiz data.

Frequent student inquiries List of issues raised in students' open-ended responses. Taken from 'muddiest point' & other student responses after text analysis

Engagement meter: Summary of what pieces of instruction students have used, for how long, etc.. Taken from log data.

Figure 1: Schematic of instructor's digital dashboard (mock-up only).

Figure 1 presents a current mock-up schematic picture of how these data are displayed to the instructor. In the upper left corner, the quiz questions students answered have been sorted by concept and the average performance is displayed. Not only are individual quiz question responses graphically represented but also each quiz question is tagged with its relationship to a concept and presented graphically as a composite performance on the concept. The instructor can then scan the list of concepts to identify those where performance was notably lower and then develop a just-in-time teaching approach, adapting one's lecture presentation to emphasize more challenging material. In preliminary use of this type of feedback applied to individual quiz questions, we have seen this approach work well in smaller classes. With larger classes and more questions, the process quickly becomes unwieldy. The availability of aggregate performance over students and questions but also indexed by concept provides greater information in preparation for more effective use of class time. Preliminary use of such data has also resulted in greater engagement of the students during class

The lower left corner of **Figure 1** presents a displaying mechanism for the output from the students' open-ended answers. Here the notion is that the instructor asked students to write their "muddiest point" inquiries, asking about topics that they did not fully understand. Currently, the display gives the instructor access to all of the student feedback by individual question asked in the lesson. The incorporation of text analysis techniques such as latent semantic analysis (LSA, Landauer, Foltz, & Laham, 1998) will increase instructor's effectiveness in analyzing, assessing and responding to student's answers to more open-ended exercises. The development and implementation of text analysis tools will allow sorting of the textual responses into categories with similar meaning, and then the instructor's dashboard would display the categories in order of frequency. For a given category, the instructor could click to see a sampling of student responses that fell into that category. Finally, the upper right corner of Figure 1 shows a simple display of the online tools and materials associated with the current module along with a means for displaying students' progress working through those materials. Note that Figure 1 is simply a mock-up of what the instructor's dashboard might look like. The idea behind the instructor's dashboard is that it offers instructors the capability of summarizing and displaying student-learning data in multiple ways. The content of the instruction can be indexed for the dashboard by item, by piece of instruction, or perhaps more meaningfully by concept. The data can then be viewed at different levels of aggregation, e.g., the class as a whole, subgroups (by major or prior knowledge), and even at the individual student level. Although we envision that the instructors primary use of the dashboard will be to gather just-in-time information on his or her students' current understanding (i.e., formative assessment for adaptation of teaching), it is also possible for instructors to use this tool for more long-term cycles of evaluation and adaptation, such as reviewing at semester's end what course materials or activities worked and what needs to be revised. For example, using the digital dashboard, an instructor could find a strong performance on a given concept throughout the semester except for the final exam questions involving that concept. This may suggest to the instructor that those exam questions were posed in a way that students couldn't recognize the concept or that the time lag until the final exam caused students difficulty. Either way, the instructor is encouraged to reflect on his or her teaching based on data and to make adjustments accordingly.

The Changing Classroom

During the 2005 academic year a five-week segment of the online Biology course was piloted in both a large (300 students) and small (24 students) classroom setting. In both cases when the online material was used the form of instruction changed for the instructor and the students. Because the online material provided interactive tools for the students to explore and self-assessments to perform, they were expected to engage with the material online before coming to class. The instructor was able to use the feedback from the participation of the students prior to class to determine areas of particular difficulty encountered by the students or self-identified by the students in imbedded, directed questions. The instructor then focuses the classroom presentation and discussion around targeted concepts, misconceptions and errors identified by the feedback. The objectives of the course are still met but the focus on learning is directed toward student learning needs. The classroom engagement is increased because the students are aware that they will be engaged with information to help their learning.

To test the value and use of each of the feedback tools, qualitative and formative assessments were carried out in the summer small course, with the students providing helpful input on points of confusions in the materials, gaps in the content, and technical difficulties. With only 24 students, the instructor easily tracked students' out-of-class progress and came to class prepared to discuss topics the students needed most. Students came to class full of questions and appeared highly engaged with the material. Based on this experience, we overhauled much of the content and further refined several activities before the fall semester.

For fall 2005, we conducted a more formal experiment using IRB-approved methods to assess the effectiveness of the online course. Two sections of the course, totaling over 300 students, were given the same introductory material online. Then, one section spent 2 weeks continuing to use the online course while the other section covered the same material in a traditional format. For the next 2 weeks, the sections reversed roles. Although there are many more results than these, here are several representative findings:

- Observations of the two sections revealed more active participation among students when they were using the online course.
- An exam given at the 3-week mark showed a slight advantage for the online section; an exam at the 5-week mark showed comparable results
- More detailed analyses of students' time spent working on particular activities showed a positive association with performance on quizzes questions testing the corresponding topics.

Summary

The strength of the assessment and analysis lies with the fact that the online system is able to monitor all of the activities of individual students and present the output based on data mining directed by specific queries. The availability of this data is the basis for the development of the extensive feedback to both the students and the instructor on a real-time basis.

Given these features, we believe the instructor's digital dashboard can provide added value over standard teaching metrics (e.g., grade books) by presenting a wide range of different assessments (not just high-stakes quiz and exam performance). In addition, the instructor's digital dashboard provides value over the most up-to-date off-the-shelf educational tools (course management systems) in that it integrates performance and usage information (rather than simply presenting usage statistics).

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