Inventing the Digital Dashboard for Learning

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Abstract: Carnegie Mellon is creating a Digital Dashboard for Learning (DDL) to enable faculty and students to tune their immediate actions (lectures, assignments, study) based on rapid feedback on student progress in learning. The DDL will provide faculty with a timely overview of student progress in blended learning environments supported by the Open Learning Initiative, Carnegie Mellon’s project to develop high quality online courses and course materials. The DDL will provide access to details of learning measurements tied to course topics and “drill down” links to original presentation materials. It will enable faculty to aggressively adapt lectures and assignments to address weaknesses in measured student performance. This paper describes the requirements for the DDL, design and implementation issues, such as modifications in associated learning objects, tagging of student interactions, data collection and analysis, and the form and content of data presentation to the faculty and students.

The Challenges

There are many challenges shared by today’s learning environments and as the size of the classes increase or the frequency of direct contact with the student decreases, the magnitude of these challenges increases. First, there is great variability in the students of today. Their background knowledge, relevant skills, and future goals make it difficult for faculty to address students’ diverse needs (Felder & Brent, 1996; Fink, 2003). Students arrive with preconceived views of the topics and a false sense of security in having heard many of the topics at least mentioned in previous, lower level 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, 2004). Third, although the conceptual structure of knowledge is clear to experts, it is not to novices. The array of new ideas and unfamiliar terminology in introductory courses tends to overwhelm students into memorizing a set of isolated facts without understanding the underlying common principles (Chi, 2005; diSessa, 1993). Finally, in many curricula, concepts are introduced initially in basic form and then applied and relied upon in multiple contexts without instruction that scaffolds these extensions of the concept to other contexts. Students who tend to compartmentalize what they learn not only become confused about the transfer of concepts to other contexts, but also miss opportunities to connect their knowledge and generalize their understanding.

From research on how students learn, two well-supported principles have emerged that can be leveraged to address 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, 2001, 2004). 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, students benefit from an explicit conceptual framework that organizes the material they are learning. Effective instruction will to make that framework explicit and salient, and students need to practice making connections between related ideas in the framework (Eylon & Reif, 1984). We believe strategies that employ these principles in a less studied area of research, namely how faculty can best use information on their students’ progress to effectively adapt their teaching, offers an opportunity for addressing these challenges listed above. Equally, we believe that digital learning environments (web-based course materials, simulations, virtual labs, learning objects of many kinds) provide an ideal context for providing immediate feedback, supplying and continually reinforcing conceptual frameworks, and, most importantly for this paper, giving faculty the data they need to adapt their instruction to the learning needs of particular classes and particular students, and provide students with better tools to monitor their own learning progress.
Many of today’s classes are deploying some form of blended instruction, supported by online materials. If properly constructed, these embedded interactive materials can provide quality just-in-time feedback to students and faculty (Bajzek, Burnette, & Rule, 2006; Smith & Thille, 2004). For example, a simulation or virtual lab can provide the student with feedback about choices and cues that can guide them to recognize their own misconceptions when the results of the lab are not what they predict. In addition, these activities in digital learning environments can provide useful feedback to the faculty (Brown, Lovett, Bajzek & Burnette, 2006). An example of a strategy for providing feedback to the faculty is the now fairly standard practice of embedding interactive questions within the text when used with web-based delivery. The students can be required to answer short essay questions before lecture. The faculty can review these answers to help channel the classroom discussion in the most productive manner, such as focusing on the key misconceptions.

Current Work

At Carnegie Mellon we are constructing an online modern biology course within the learning environment of the Open Learning Initiative (OLI) at Carnegie Mellon (http://www.cmu.edu/oli). This course integrates textual explanations, animations, simulations and other interactive content. Importantly, our designs of all the materials are taking into account the need to provide timely and targeted feedback for the students and real-time student progress reports for the instructor. Our goal is to create an online learning environment that engages the student, improves learning and allows immediate adaptation of instruction based on substantial data about class performance. We have deployed the first two modules of this course to over 350 students over the past two Fall semesters, as well as to 25 students enrolled in an accelerated summer session. The overall response we have received from students is that they are anxious for us to integrate interactive online learning tools into more of the course. We have used students’ comments on aspects of the course to refine what is already built and to inform our additional modules’ design. Beyond collecting students’ reactions to the online learning environment and their feedback regarding specific suggestions for improving it, we have engaged in two studies both of which focus on students’ learning outcomes as a function of using the OLI-Biology course. The first of these involved a comparison of two groups of students taking introductory Biology and related their learning outcomes to different parts of the course in which they learned with and without the OLI-Biology materials. The second focused on the relationship between students’ degree of engagement with the OLI-Biology materials (e.g., time on task, number of interactions, etc.) and learning outcomes for a group of students who all had access to the OLI-Biology materials. Although analyses are ongoing, preliminary results suggests that (a) students learning with the OLI-Biology materials perform at least as well as students learning with traditional (i.e., textbook and standard lecture) methods and (b) the more students interact with the OLI-Biology materials for a particular topic, the better they perform on assessments specific to that topic. Even with these encouraging, preliminary results, the instructor teaching with the OLI-Biology materials expressed a desire to be more connected to students’ progress and learning throughout the semester. Given the research mentioned above about the value of effective and timely feedback, and given the easier access to student data through our online environment, we began exploring ways to give useful information to the instructor about students’ learning in the OLI-Biology course and to provide similar information to students to inform their own self-assessment of learning.

The Digital Dashboard

Reviewing a class’s answers to multiple-choice questions is of limited value. Reviewing text responses from a large lecture class is more informative, but also so labor intensive that few faculty have the time to do it. How do we take adaptive instruction to the next level by providing significant easy-to-use, and easy-to-interpret feedback to faculty? A vibrant interactive online environment should provide not only students but also faculty with many opportunities to interact with feedback-rich instructional materials. Our ultimate goal in creating a Digital Dashboard designed for Learning (DDL) is make a tool both for students and faculty. We are starting with faculty teaching in blending models of instruction. Given today’s demands, faculty do not have much time to analyze such data and construct the appropriate reactions to it. We believe a new tool needs to be invented to assist in processing and displaying this rich data: a Digital Dashboard designed for Learning.

A simple definition of a DDL is a tool that provides visibility into key indicators of student learning through simple visual graphics such as gauges, charts and tables within a web browser. Dashboards are appealing because they
• Provide a wide variety of different metrics in a single consolidated view
• Roll-up details into higher level summaries
• Provide intuitive visualizations that are instantly understandable – for example, red bars mean a problem
• Provide linkages to the data they represent

We want to design for faculty an efficient but meaningful tool that provides visibility to Key Learning Indicators (KLIs) to help understand where the class stands in the learning process and what corrections faculty can make. For students, a personalized view of the DDL can enable the individual student to understand his/her own learning achievement in the course and provide links from the student DDL to suggested review areas.

Assuming an interaction-rich and instrumented learning environment, connecting the diverse data sources on students’ learning will be accomplished through tagging the data to report KLI details, data gathering mechanisms and analysis algorithms that correlate, analyze, and summarize the data and then feed it to a visualization tool, the DDL. Just as the dashboard in a car displays key information (e.g., current speed) that the driver needs in order to adjust his or her driving appropriately, an instructor’s DDL 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 might be displayed on the instructor’s DDL. The diversity and richness of these data highlight the unprecedented opportunity we have for keeping faculty in tune with the many aspects of students’ learning. Note that these data sources may either be automatically transferred to the dashboard from stand-alone versions of data gathering tools and materials, input from external sources (e.g., gradebook, course management systems), or directly linked via the integrated components of an online course. The design (and refinement based on use) of the instructor’s DDL presents this information in a concise view that is both easy to use and flexible enough to meet instructors’ changing goals.

The primary research problem to creating this DDL will be the tagging and logging of student interactions with various tools in the digital learning environment to provide meaningful KLIs for the DDL to process and display. Simplistic tags, such as concept name/keyword page hits are not sufficient. (It is worth noting that current “course management systems” offer faculty little more than “pages visited” data and quiz answers to use in adapting their instruction.) Multi-dimensional rubrics will need to be deployed to accurately measure progress: cognitive processes, types of knowledge, student engagement, and concepts will all play a role.

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Table 1:
Sample student-learning measures called from data

| Assessment by concept: Calculation of % correct on particular concepts. With quiz items indexed by concept tested, taken from quiz data. |
| Frequents 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:** Elements of instructor’s DDL (mock-up only).

Fig. 1 presents a mock-up schematic of how diverse, pre-analyzed data might be displayed to the instructor. In the upper left corner, the quiz questions students answered have been sorted by concept and the measured 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 deficient, and then adapt his or her current teaching appropriately, changing the next lecture presentation to emphasize what he or she now understands to be more challenging material for this particular class. We have made preliminary use of this type of feedback applied to individual quiz questions and we have seen this approach work well in smaller classes. With larger classes and more questions, the manual scanning process quickly becomes unwieldy requiring DDL tools for grouping and reporting. The availability of aggregate performance by students on questions provides information to enable more effective use of class time. Preliminary tests indicate that the use of such data has also resulted in greater engagement of the students during class.

The lower left corner of Fig. 1 presents a mechanism for accessing 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 development and implementation of text analysis tools should allow separation 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 Fig. 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 some elements of KLI aggregation the instructor’s DDL might contain.

The concept of the instructor’s DDL is that it offers instructors the capability to see data on student learning 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/her teaching based on data and to make adjustments accordingly.

Given these features, we believe the instructor’s DDL can provide added value over standard teaching metrics (e.g., gradebooks) 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.

Although this paper focuses on the DDL as a tool to enable the instructor to understand the learning status of the students in the class, the same principles apply to creating a student DDL to enable the individual student to understand his/her own learning achievement in the course and provide links from the student DDL to suggested review areas.

**What is required to create a DDL?**

A number of elements must be researched, designed, implemented and tested to implement a DDL:

1. Construction of Interactive Learning Objects, designed to provide immediate feedback to students as well as data to the dashboard
2. Tagging of all materials with Key Learning Indicators and keeping learning units tied to clearly articulated learning objectives
3. Collection of data by the Dashboard server
4. Real time data-mining and analysis of data
5. Construction of Dashboard to display information intuitively and allow the learners and instructors to interact with (be guided by) this information

1. Construction of Learning Objects

Embedded interactive materials are key components of active learning environments. These materials or learning objects, such as virtual labs and simulations, must be tied to the learning objectives of the unit where they reside and provide open-ended exploration for the student (NRC, 2003). The simulation or lab can provide behaviors and cues to guide student learning and understanding. However, they must also explicitly prompt the students to analyze these cues, either as activities or questions embedded within the material or companion to it. Results of the students’ interactions need to be sent to the dashboard server for analysis and display.

2. Tagging of all Student Interactions

In order for tools to analyze and display KLIs, all of the interactions will need to be tagged so that the data they provide contains information about the student’s level of understanding in aspects of the concept or topic area they are interacting in. How these interactions are tagged to represent KLIs represents a significant research problem. Simplistic tags such as concept name (keyword) or level of interaction (page hits) will not be sufficient. Multi-dimensional scales will need to be deployed to accurately measure progress: cognitive processes, types of knowledge, and concepts will all play a role. Rubrics for these scales will need to be defined and then applied in all objects of each unit. The learning objectives for the unit as well as the entire course will determine one of the scales. Instructors will need to be guided in specifying these objectives and aligning all of the components of the module with these objectives. Designing traditional learning objects (e.g., multiple choice questions) to map to clearly articulated learning objectives and the KLIs for the materials in the units is tedious and pedagogically difficult. Consequently, the authoring tools used to create or insert these objects (assessments, tutors, animations) should provide an infrastructure to facilitate the tagging of these units by the instructor at the time of creation/entry. As OLI begins the design for their new assessment engine, efforts to support robust meta-data tagging and reporting through a DDL are underway. Our first DDLs will be developed for the introductory biology course and a sophomore biochemistry course.

3. Data collection

For the purposes of creating our first DDLs, we are currently leveraging the existing resources within the learning environment of the Open Learning Initiative (OLI) at Carnegie Mellon (http://www.cmu.edu/oli). OLI currently collects and displays a number of student feedback interactions to the instructor. In addition, it’s rigorous logging services allow course developers to collect significant data that can be mined, though currently not in real-time. As learning environments become more diverse and collaborative, the data collection will need to become more robust and able to accommodate other course management systems as well as data coming from multiple sources.

4. Data Analysis

There are several classes of data analysis tools that will need to be created and deployed to make the dashboard successful. First, many of the student interactions are of the open-ended, exploration, reflection type. The data they provide will inform the instructor, but should also provide feedback to the students in an automated fashion, since the instructor will not have time to provide individualized instruction to a large class. We currently have several versions of tools that allow the students to answer open-ended questions and then compare their answers with prototype answers. The students are required to include at least a few key words before they are allowed to view the prototype answer. They also know that the instructor will be viewing their answers.
Needed are automated tools that can learn from prototype responses, place student responses into groups and delivering general correct feedback to groups of responses thereby providing students timely feedback. Grouping student responses would simplify the DDL’s task of presenting data to the instructor. It would be good to provide tools facilitating instructor reactions to outlier student responses. In addition, tools will need to be created to aggregate and analyze the KLI data so that it can be represented in the DDL and linked back to meaningful details for the instructor or student to review. The complex rubrics required for measuring learning will be more difficult to process than average values or distribution of answers, although these common gradebook measures will be desired to complement the KLIs where available.

5. Dynamic Dashboard Presentation

While all the other parts of the system supporting the display of the data within the DDL are important and must be crafted carefully to insure the success of the process, the key element will be the intuitive and almost emotional rendering of the KLIs. An effective DDL display cannot be as complicated as the sample in Fig 1. Although the instructor will need the ability to drill down to display any of those elements of KLI information, the outer layer of the presentation must be simple enough to enable the instructor to recognize quickly the status of the KLIs for the course. The DDL display must provide a snapshot impression of the current state of learning about current topic or unit along a number of dimensions as provided by the KLIs. Thus, the DDL display must display a snapshot of the state of the KLIs for the current topic or learning unit.

As an example of a dashboard style of visualization, consider the dashboard for the stock market domain in Fig. 2. While the DDL we develop might not use the same representation, this example can serve as a model, because it makes it easy to recognize the general status of the market in this snapshot, and provides a simple overview of a massive amount of detailed information.

Figure 2: The chart uses shades of green to indicate price increases; red to indicate decreases. Sizes of the blocks represent sizes of companies. The white borders group companies into related industries. A DDL could make use of similar markup to represent concepts, grouping them into learning units or chapters. http://www.smartmoney.com/marketmap/

Without knowing much about the stocks or the numerical data represented within this display, you are immediately drawn to the two areas in bright red in the lower right. Rolling the mouse over them exposes the first layer of underlying information, and clicking drills down into further details. In a DDL, an area looking like the Energy block represented in shades of dull red in the upper right of the example might indicate a content area new to the students, or a concept not clearly understood. The Map Control Panel at the right of Fig. 2 lets you control the
parameters of the market display. A different, but analogous, set of controls would be needed to allow customization of the DDL.

The stock market dashboard reveals detailed dynamic numeric information and (usually static) company information as you drill down into the details. A DDL would need to represent dynamic information about the measured KLIs at the first level. Drilling down into a DDL would expose the concepts covered, the type of mastery achieved or found lacking, and links back to source materials, including the actual course presentations. Thus, the DDL would identify not only the assessment item that measured a particular KLI, but also the original presentation of the material being measured.

Example of Simulation Providing Feedback to Student and Instructor via Dashboard

As a representative example, consider the goal of teaching students about protein-ligand binding. The learning objectives that are associated with this topic are:

i) Understand the molecular basis of equilibrium and be able to recognize systems at equilibrium.
ii) Understand the molecular basis of La Chatelier’s principle and be able to predict how a system will behave when it’s not at equilibrium.
iii) Understand that biological reactions, due to their specificity, can be saturated. They should be able to extend this concept to other systems, such as signal transduction.

To help students achieve this/these learning objective(s), we have developed a virtual lab on protein-ligand interactions. In one particular laboratory, the student is able to vary the concentration of oxygen with a slider bar and then see – via the simulation – how this concentration affects the binding of oxygen to myoglobin. (Other versions of the lab allow for other molecules to be manipulated and their binding rates to be simulated and tracked through the simulation.) Besides building this simulation to be “biologically correct”, it was specifically designed to be interactive, asking students questions at various points about what they are seeing in the simulation, what hypotheses these simulation results would support, and what predictions they have for novel conditions? Students’ responses to these questions are automatically logged and thus form a potential data source that can feed into the DDL. A critical aspect, however, lies in the ability to accurately infer students’ knowledge from their interactions with the system. We have addressed this by tagging the various questions (and even particular student responses) with different concepts and different levels of understanding. For example, after the student has worked with the simulation and answered some preliminary questions, the following questions would be posed:

2a. When the amount of oxygen is increased, the amount of oxygen bound to myoglobin:
   i) increases [They probably understand La Chatelier’s principle]
   ii) remains the same [They probably don’t understand La Chatelier’s principle]
   iii) decreases [They definitely don’t understand La Chatelier’s principle]

2b. As more and more oxygen is added to the solution, the amount of bound oxygen:
   a) increases without limit. [Indicates confusion with regard to saturation.]
   b) becomes equal to the number of myoglobin molecules. [Indicates that they understand saturation.]

Note, that the first question focuses on La Chatelier’s principle (and is so tagged) whereas the second question involves the concept of saturation. Moreover, depending on students’ answers, the system gets information not only about whether the student has answered correctly but in some cases whether they have fallen prey to a common misconception or perhaps demonstrate a partial (rather than complete absence of) understanding.
Aggregating over data such as these, the digital dashboard might have collected 10 responses from a given student that all involve La Chatelier’s principle. These data are then analyzed. (A variety of ways are possible; most simply, a straight proportion correct can be computed but more complex learning models can also be applied to the data.)

Then, the results of such analyses are fed to the user interface displaying the results such as in Fig. 3.

**Conclusion**

While we have become convinced that a tool such as a DDL can be a very effective tool in assisting instructors to monitor the learning of their classes, we are just beginning on this journey to creating and testing such a tool. As described in the requirements above, it is clear the most difficult research problem is that of recognizing and tagging the KLIs within the system. The other aspects of the Dashboard are more issues of implementation than discovery. An effort of this magnitude will require resources, research and development, deployment, and assessment of the various tools and techniques required. We are very interested in collaborating with others who are interested in participating in this project.

**References**


