Improving Animation Tutorials by Integrating Simulation, Assessment, and Feedback to Promote Active Learning

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Abstract: A multidisciplinary team of biologists, media programmers and educators have been constructing detailed animated tutorials describing complex biological processes to facilitate students' understanding in the Modern Biology and Biochemistry courses at CMU. This paper describes the evolution of these tutorials into active learning environments. We have integrated feedback techniques relying on mathematical models within simulations to provide problem-based learning interactions and promote a deeper understanding. Furthermore, we have integrated self-assessments within the tutorials, so the students will be able to test their knowledge by interacting with animations, answering questions, and receiving multiple levels of feedback. These online environments provide a continuous flow of student interaction and performance data. We plan to include this data into our Digital Dashboard for Learning (DDL), a dynamic portal providing an overview of the students' performance, to improve teaching and learning.

Introduction

One of our earlier projects, sponsored by the Howard Hughes Medical Institute, involved creating detailed animations of complex biological processes to improve understanding of some of the main concepts taught in Modern Biology and Biochemistry. A team of biologists, media programmers, and learning experts has been meeting regularly to explore ideas from multiple perspectives, to examine knowledge acquisition at different levels of abstraction and to create animated tutorials that facilitate students' coherent construction of knowledge. These meetings have resulted in the creation of more than fifteen flash tutorials that are used by instructors during the live classroom presentation and also by students for study and review purposes.

Since student 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), we recently started to explore ways we can motivate students to take responsibility for their own learning and become "Primary Investigators" in their studies by enhancing these tutorials. This scenario requires that the learners themselves use (and not just watch) the animations. We are designing ways to vary the degree of interactivity in these animations, to focus attention and to provide comprehension checks and feedback. We are also designing ways in which the tutorial environment can provide useful information back to the instructor by logging student interaction and performance data that can be analyzed and dynamically presented to the instructor in real time through the Digital Dashboard for Learning tool (DDL)(Brown, W., Lovett, M., Bajzek, D. & Burnette, J. 2006), a new tool under development within the Open Learning Initiative (OLI) (www.cmu.edu/oli) (Smith & Thille 2004).

This paper describes the tutorial environment used in the Modern Biology and Biochemistry courses. The current versions of these animations are publicly available at: http://telstar.ote.cmu.edu/biology/animation/. Furthermore, the paper will describe our application of innovative feedback techniques to connect concepts from within the narrative to concrete visualizations in real time. Our goal is to transform our tutorial environment into a more effective teaching tool as well as a more effective learning environment for students.

Animation & Science

The goal of science courses is to aid the students in understanding the underlying physical laws that are responsible for observed phenomena. Meeting this goal is especially challenging in biology courses due to the complexity of the systems involved and the spatial and temporal nature of many biological processes (Rule, G., & Bajzek, D. 2005). Furthermore, a series of empirical studies demonstrated that animation serves several instructional roles: attracting and directing attention; representing domain knowledge about dynamic processes; and explaining complex phenomena (Park, 1998; Park & Gittelman, 1992; Rieber, 1990).

Research suggests that the use of multimedia, including animations, to teach difficult scientific subjects will allow a broader base of students access to new learning since the visual cues available will reach individuals with various learning styles (Heyden, 2004). Moreover, if designed correctly, multimedia can assist students in constructing, perceiving, and conceptualizing the complex scientific systems that are part of our world.

We first researched and then constructed flash tutorials designed to satisfy the following criteria:

- include the most scientifically accurate information while presenting a process in an unambiguous manner so students do not adopt misconceptions about the process,
- help redirect and focus students' attention in specific areas,
- help students visualize what is not readily seen,
- allow students and instructors to directly interact with navigation controls to freely explore the content,
- stimulate recall of prior concepts and transfer of concepts to mental models being constructed.

We believe our flash tutorials can assist students in developing a more complete understanding of many fundamental processes.

Tutorial Template Design.

Our goal in designing these animations is to provide interactive and flexible controls to accommodate various student-learning styles. With the help of assessment experts, we have integrated these animations into a tutorial delivery environment that incorporates three main components (see Figure 1).

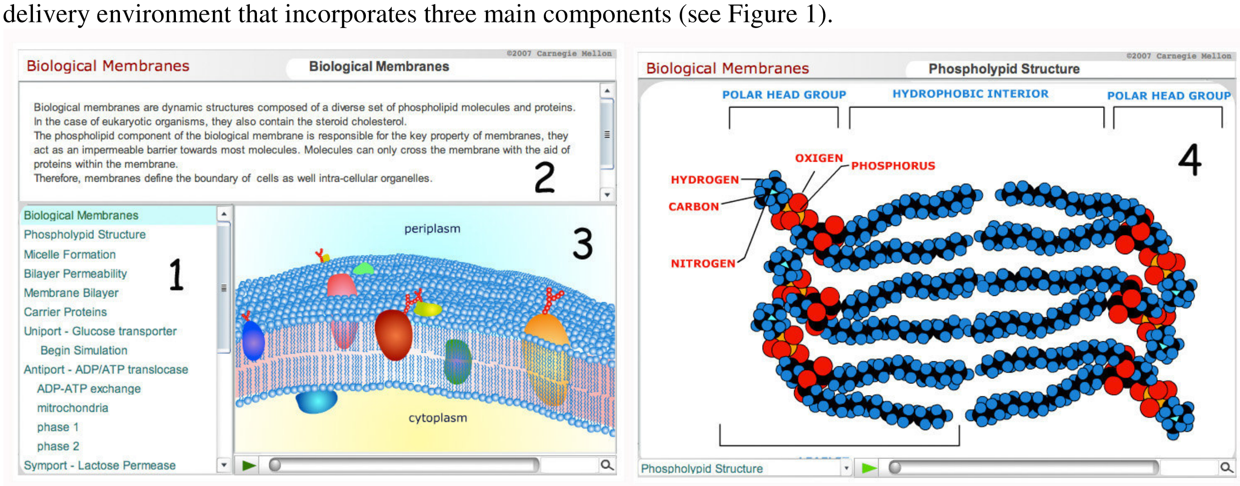

Figure 1: The integrated tutorials environment on the left; the zoomed presentation view on the right. (1) The outline navigation component. (2) The text/narrative component and (3) The animation component and its controller. The controller includes a magnifying glass to enlarge the animation for in-class presentation (4).

1) The outline/navigation component.

It has been shown that dynamic and temporal aspects of multiple elements in system-controlled animation may impose additional perceptual and cognitive processing demands on learners as they attempt to perceive and comprehend the animated content (Lowe, 2003). To overcome those demands we developed a flexible format of direct navigation for the animations. This allows learners to directly interact with controls and freely determine their path through the animations. Learners' interactions with the interface are rapid, incremental, and reversible, with results being immediately visible. This navigation tool also provides a visual overview of the process to the student. Each step of the animation is represented with a title listed in the left window. The user can navigate by clicking on the title of the step of interest. At the same time, the user can also navigate through the tutorial with the basic controls (play, stop, timeline slider) localized on the lower part of the animation shell.

This construction should help the instructors to navigate through the animation and jump as needed to review any given step at the students' request. Additionally, research shows that too much visual information, presented simultaneously, creates an attention overload (Huang, Zary, 2003). Our tutorials are broken into this series of short clips rather than complete complex animations.

2) The text/narrative component located on the very top.
Each step includes descriptive text that the students should read before watching the animation. This text describes in a comprehensive way what the reader will see and should watch for in the animation window below it. The text prepares the students by bridging connections between verbal and visual representations. Our approach is in agreement with previous work from (Mayer and Moreno 2002) that demonstrated the power of the "Multimedia Principle" combining animation and narration to promote deeper student learning than a narration alone in the form of a lecture.

3.) The animation component with its controller.
This window allows the display of a series of short clips one after the other. The controller is designed to play the animation, pause when needed, and to zoom the animation. When the zoomed mode is displayed, the animation takes over the tutorial window and the text window is not displayed. This mode can be used to enlarge the animation stage for classroom presentation by the instructor or by the students to watch the material. We have found that having a common controller/navigation area for all animations focuses the student's attention on the details of the animation instead of having to learn a new control system for each animation that they view. Furthermore, having a common control mechanism greatly reduces the time required to design new animations (Rule, G., & Bajzek, D. 2005).

Flexible Template Architecture

To optimize the accessibility of the tutorials to instructors, we have developed a flexible architecture using eXtensible Markup Language (XML) to shape and control the delivery of the flash files (see Figure 2). Our macromedia flash "stage" displays each tutorial component as described by the XML "storyboard" file. This XML file contains the structured information (i.e. content narration, short clips, and outline navigation). The instructors can quickly rearrange the steps, and modify the outline text and the narration. Each XML file is designed to be understandable, concise and user-friendly. Furthermore, this system allows us to repurpose the short clip in different scenarios and views and gives the instructors the flexibility to use the animations as needed.

```xml
<TUTORIAL thisTitle="DNA Replication">
    <step stepURL="swfs/initiation7.swf" menustep="Replisome at one fork">
        <text>The final steps in the assembly of the "replisome" involve the
            binding of DnaG (primase) protein next to the helicase, and the loading of two DNA
            polymerase III holoenzymes at each fork. RNA primers (red) are synthesized on both
            strands at the fork. DNA Pol III is a large multisubunit enzyme. The β-subunit is shown
            as a blue ring attached to the rest of the enzyme; it is the "essential processivity
            factor"</text>
    </step>
    <step stepURL="swfs/elongation.swf" menustep="Elongation of leading & lagging strands">
        <text>The RNA primers are extended by DNA Pol III (continuously on the
            leading strand and discontinously on the lagging strand). Synthesis of the daughter
            strands requires the unwinding of parental DNA by DnaB helicase (with ATP hydrolysis).
            The positive supercoiling that results from replication fork movement is removed by DNA
            gyrase (with ATP hydrolysis). Each DNA Pol III synthesizes DNA at about 1000 nucleotides
            per second. (This animation is a "super-slow motion" version of the real events, i.e.
            ~15 nucleotides/min.)</text>
    </step>
```

Figure 2: Example of an XML file. The Instructors can change the navigation labels in red as well as the text in black and rearrange the outline by changing the order of the steps.

Integration of the simulation environment into the tutorial environment.

Our current *animations* use step-wise sequences of diagrams, numbers, or images to illustrate complicated concepts or theories. In these animations we

- emphasize the important parts of a subject by removing unnecessary and distracting details,
- visually present an overview of the process or mechanisms that would be difficult to illustrate in the real world, and
- direct the viewers attention to salient points of the process.

By illustrating a given process evolving over time the animations allow the student to gain an understanding on how a system progresses from one intermediate state to another.

Recently, we have created more *interactive simulation environments.* These activities are based on mathematical models while providing appropriate visual representations (Bajzek, D., Burnette, J., & Brown, W. 2005; Rule, G., & Bajzek, D. 2005). They represent interactive learning opportunities for the student allowing them to explore the behavior of a physical system at a much deeper level than was previously possible. (National Research Council, 2003).

We are using *simulations* to provide learners with:

- the possibility to actively participate and change the course of the processes,
- direct experimentation with and data analysis of system models, and
- multiple representations of concepts.

Most recently, we have begun integrating the *animations* and *simulations* within the same tutorial environment, using simulations driven by mathematical models and behavioral rules to provide more realistic animations. In this case, the role of the students is still somewhat passive. To increase the active participation of the students, we are now experimenting with better storyboards that more effectively combine animations and simulations designed to allow students to experiment within the simulations, changing parameters and analyzing the resulting behavior. We believe combining both will provide the student with a richer environment for learning about biological processes while promoting a deeper understanding with problem-based learning interactions. Moving back and forth between demonstration and exploration, the student will be challenged to test their knowledge before moving on to something new.

The following two examples illustrate how we propose combining the simulations with the animations:

> 1) In the biological membrane tutorial, which explains the structure and function of membranes, we propose to integrate the Isotonic Equilibrium Simulation. This will give the students the opportunity to experiment with Osmosis, a selective diffusion process driven by the internal energy of the solvent molecules, by adding sodium ions to one side of the membrane and observing the behavior of the system.
>
> 2) A second example is to integrate the Enzyme Catalysis Simulation into the Signal transduction animation. In this case, the student will learn how the binding of a ligand to its receptor ultimately leads to the production of high levels of cAMP, an important second messenger in the signal transduction pathway. The students can manipulate the number of the ligands that can bind to the receptor.. Once bound, the ligand, can either simply reversibly come off the receptor, or it can cause the production of cAMP..

Integrating Mini Cognitive Tutors into the Tutorial Environment.

As we move forward with the development of these tutorials, we've begun to integrate additional assessment activities into our tutorial environment to further guide student learning. While integrating these activities it is important to keep assessments, learning objectives, and learning activities clearly aligned. These new assessments allow students to interact with the simulations, provide answers to questions, and receive hints and feedback. The quantity and quality of these activities will help them improve their understanding of the material.

We are currently deploying our set of tutorials within the online Modern Biology course that is part of the Open Learning Initiative (OLI) at Carnegie Mellon. OLI course development is guided by the best available research from the cognitive and learning sciences. This research shows that students who frequently interact with the learning materials perform better when tested later on the materials. These interactions take the form of learning activities, comprehension checks, and timely feedback.

We have been deploying small OLI mini cognitive tutors, embedded within the text pages, to provide scaffolded, comprehension checks to the students. Mini tutors present students with data analysis problems and guide them through the solution as needed. Furthermore, they support students with hints and feedback. These activities aim not only to increase motivation but also to provide tools for both the students and instructors to monitor the students' learning progress.

To vary the degree of interactivity and bring the value of these mini-tutors even closer to the learning activities, we are now working to integrate these mini-tutors into the tutorial environment. Earlier work by Dancy and Beicher indicates that animations can be used to increase the validity of assessment (Melissa Dancy and R Beichner, 2006). In particular, students appear to be more likely to misread or misinterpret a static question with words and pictures than a question with information conveyed in an animation. In addition, students appear to learn more effectively if they are given complementary and mutually reinforcing information over visual channels (Clark and Mayer, 2003).

Tutorials with tightly coupled animations and assessments provide more contextual richness to the students. This allows them to freely navigate and interact with the animations to help them understand the intent of the questions and provide answers that more accurately reflect their understanding. In addition to providing hints, the tutorial environment can provide different pathways through the animation to visually explain the results of students' assessment choices. The assessments can also be used to focus the students' attention on the more salient points of the tutorial. We can provide pools of questions for some steps of the menu and randomly deploy them to allow students to practice each time they revisit the tutorial.(Figure 3).

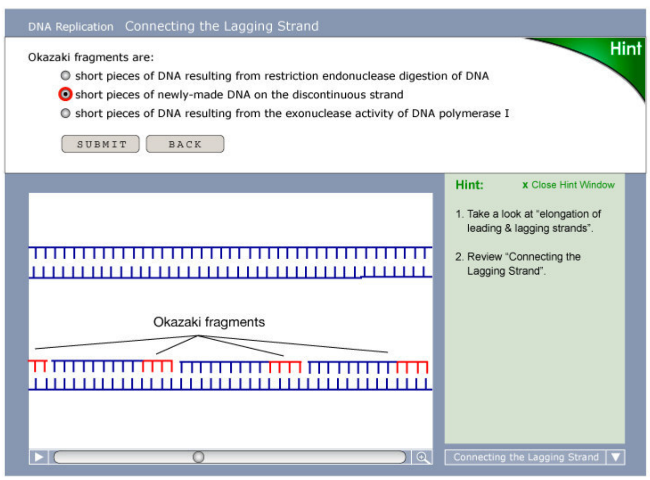

Figure 3: mini tutor (with hint button) replaces the text window providing questions, hints, and feedback.

Feedback and Digital Dashboard for Learning (DDL).

The tutorials provide multiple levels of feedback to students. This feedback will help them monitor their own learning progress, supplying and continually reinforcing the conceptual framework. The feedback includes:

- guided instructions with pointers to reinvestigate a topic, fact or concept before progressing to the next stage of the animation;

- hints to help reframe the question; matching open ended responses with model responses (provided only upon completion of the student's response);
- correctness of answers;
- visual aids reinforcing key concepts.

Student interactions within the tutorials also provide useful data that can inform the instructor on student learning. A recent project within the OLI is to create a Digital Dashboard for Learning (DDL) where the continuous data provided by student use of online instructional tools and assessments (Brown, W., Lovett, M., Bajzek, D. & Burnette, J. 2006) can be turned into dynamic information the instructor can use to shape the delivery of the course. The goal of the DDL is to visually provide a quick overview of the students' performance to the instructor through simple visual graphics such as charts and tables within a web browser. This overview will help the instructors monitor students, visualizing where the class stands in the learning process. The instructors can alter the presentation of their course material to match the current progress of the students.. The DDL will provide students with a better understand their own learning achievement in the course and can provide links to suggested review areas.

The DDL will give a unique opportunity to organize information, categorize answers to open-ended questions and provide a use-index to better inform the instructors on students' learning progress. Furthermore, it will allow the future optimization of the tutorials and provide useful data for research on students' learning.

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