An Online Heart Simulator for Augmenting First-Year Medical and Dental Education
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INTRODUCTION

Medical education has always faced a conceptual challenge: how to connect the elegant abstractions that underlie basic science to the complex physiological processes of the living body. Every physician — and every overwhelmed first- or second-year medical student — is all too familiar with the alarming cognitive leap between the idealized representations found in textbooks or lectures and the messy realities of the clinical setting, where pressured practitioners must consider the interplay of multiple variables. (How does this individual patient's physiology vary from statistical norms? Behind the ambiguous signs and symptoms in the clinical presentation, what chronic and acute disease states, drug effects, and other factors might be at work?) In the constant effort to increase students' comprehension of a large and expanding body of knowledge, biomedical educators have found that the transition from passive memorization to active application of basic principles is a formidable speed bump. However, the imaginative use of information technology now offers the student a powerful boost toward the ultimate goal of becoming a sophisticated, perceptive, and effective physician.

Drs. Daniel Burkhoff and Marc Dickstein of Columbia University's College of Physicians and Surgeons have joined with the Columbia Center for New Media Teaching and Learning (CCNMTL) to develop an online model of human cardiac function, the first in a projected series of dynamic simulations of physiologic entities and concepts. The CCNMTL Heart Simulator (Figure 1) visually represents the mathematical relations among ventricular pressure and volume, heart rate, filling pressure, afterload, and cardiac muscle contractility as an animated interactive graph, which pulses in real time (reflecting a living heart's systole/diastole cycle, known as the Pressure Volume or PV Loop, see Figure 2) and responds both visually and numerically to changes in each variable. By manipulating these parameters, observing immediate results, answering questions, and referring to related course material in linked windows, a student can hone his or her understanding of the fundamentals and complexities of cardiology.

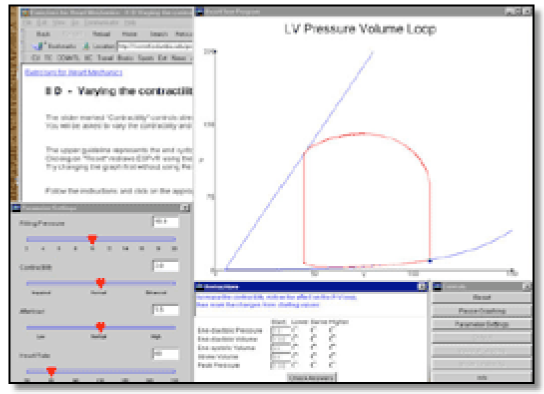

Figure 1. Screenshot of Heart Simulator

The initial version of the Heart Simulator has been implemented in a core physiology course for Columbia's first-year medical and dental students, Science Basic to the Practice of Medicine and Dentistry (SBPMD), as both a lecture tool and a testbed for individual experimentation. For the student who gains hands-on experience with the principles of heart function through this innovative program, the hope is that mastery of important biomedical content is both accelerated and deepened.

As Dr. Frank Moretti, executive director of the CCNMTL, has stated, the World Wide Web has enormous potential to move beyond its current status as a delivery system used largely for text; though most users continue to regard the Web as essentially a publishing medium, its capacity for interaction in multiple media offers great opportunities to enrich the practices of teaching and learning. The development of a more complex and varied "culture of use" goes hand in hand with the development of appropriate digital tools, and CCNMTL has been a pioneer in that twofold effort. The disciplines of physiology and particularly cardiology, where measurable but complex phenomena can be represented by mathematical equations with a regular temporal component, are particularly well suited to the real-time visual interactions that a well-designed Web program can provide.

The Heart Simulator grew out of the perception by Drs. Dickstein and Burkhoff that the quality and pace of instruction in basic physiology could benefit immensely from the translation of conventional instructional material into digital media. Throughout the biomedical curriculum, but particularly in core courses like SBPMD, instructors have always faced a formidable "pressure/volume curve" of a different sort: the volume of material that students need to master is enormous, and the limited time available for this learning creates a form of pressure that is inimical to the attainment of thorough comprehension. Students' progress in converting a flurry of disconnected information into a coherent grasp of body function is by no means efficient or straightforward. Most medical students do come to understand and apply the necessary principles, but any innovation that accelerates and deepens this process is a boon to students and faculty alike (not to mention the ultimate beneficiaries, the patient population). Studies on design principles for computer-assisted constructivist learning environments support this approach[2].

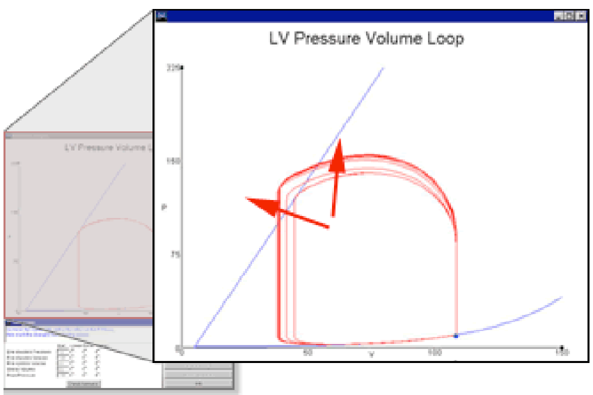

Figure 2. Pressure Volume Loop screenshot from Heart Simulator

Drs. Dickstein and Burkhoff originally created the predecessor of the CCNMTL Heart Simulator as a private program for augmenting lectures in the cardiologic segment of the yearlong SBPMD course[1]. Quickly realizing its potential to breathe life into lecture material and allow students to study and experiment on their own, Drs. Dickstein and Burkhoff worked with the CCNMTL staff to create the first working prototype for use on the Web. The program comprises a set of modular applets in the Java programming language, allowing compatibility with any Java-enabled browser and facilitating interactive operation from any computer connected to the CCNMTL's site through the Internet. A pilot usage of the application in a summer undergraduate program of 100 students received enthusiastic reviews from student participants and faculty, along with useful suggestions for improvements that were implemented in the version now used in SBPMD. The online course materials for SBPMD in the 2001-02 academic year incorporate the Heart Simulator in password-accessible pages used by all first-year Columbia medical and dental students.

In a review of the state-of-the-art in heart simulators, only one suitable competitor was found, SimBioSys, developed by Critical Concepts Incorporated[3]. CCNMTL engaged an evaluator to test SimBioSys and found it to be a powerful and useful program. However, its broad purpose as a complete body simulator, its challenging interface, and the fact that it is only available via cd rom gave us confidence that a focused, web-based, simple-to-use program based on a sophisticated mathematical model could have great advantages for first-year medical curriculum.

METHODS

The course schedule for medical and dental students crosses two semesters with each semester divided into weeks. During weeks ten and eleven, the students are exposed to Heart Mechanics. Dr. Dickstein, Course Director of SBPMD, presents the Pressure-Volume relationship in his lectures on Mechanical Properties of the Heart and in a corresponding workshop. The total number of students enrolled in the 2001-2002 academic year was 206, of those 139 were medical students and 67 were dental students.

The design used was a single group studied only once, subsequent to some agent or treatment presumed to cause change. The lecture where the Heart Simulator was presented represents the intervention and the Survey represents the observation or evaluation study. Several methods were used to collect the data: student's questionnaire, faculty questionnaire and observation. It is important to mention that medical and dental students have almost the same course schedule, and their time is very limited. Therefore we chose not to videotape students using the simulation. The final version of the Survey has a total of 23 items on a Likert Scale and 3 open ended questions.

A Faculty Survey administered to the Course Director of the SBPMD in order to explore areas in which the Simulator might be improved was also used. In addition to quantitative data collected by questionnaire, qualitative data derived through observation of the lectures by the Evaluator and the Programmer, who attended the lectures when the Simulator was presented to the students.

RESULTS

The following tables present the most relevant results of the questionnaire.

Question Item	Agree	Unsure	Disagree
Relied Extensively on heart simulator	64%	14%	22%
Relied Extensively on written resources	92%	5%	3%

Table 1. Heart Simulator use in addition to use of conventional written materials.

Question Item	Not at all	30 min to 1 hour	2+ hours
Before related lectures, I used the Heart Simulator…	66%	20%	14%
After related lectures, I used the Heart Simulator…	14%	50%	36%

Table 2. Student use of Heart Simulator relative to related lectures.

Question Item	Agree	Unsure	Disagree
The Heart Simulator was useful for learning:			
events that occur at different points in the cardiac cycle	80%	15%	5%
the relationship of loading conditions and cardiac output	87%	12%	.5%
the relationship between ventricular pressure and volume	84%	12%	4%
to draw and label the pressure volume loop	82%	12%	6%
the Starling relationship	51%	28%	12%
how changes in preload, contractility and afterload affect the pressure volume loop	92%	7%	2%
how to recognize or identify normal pressures in the heart	53%	32%	15%

Table 3. Heart Simulator's perceived usefulness for learning cardiac-related course objectives.

Question Item	Agree	Unsure	Disagree
I had no trouble accessing the Heart Simulator.	82%	9%	9%
I found it easy to learn.	87%	10%	3%
The instructions were easy to follow.	86%	13%	1%
The screens of the Heart Simulator are well laid out and easy to follow.	83%	13%	7%

Table 4. Heart Simulator's ease of access and usability.

Usage in addition to conventional methods (Table 1). The results show that two-thirds of the respondents made extensive use of the simulator in addition to their reliance on conventional means of studying. However, students continued to devote significant time to written materials.

Use relative to related lectures (Table 2). While it is not surprising that most students did not try the heart simulator prior to related lectures, it is interesting that a small group (14%) used it for at least two hours. As expected (and as the simulator was designed for the course) 86% of the students who used it did so after the related lectures.

Perceived Usefulness for learning course objectives (Table 3). There was a major consensus perceived by students that the Heart Simulator assisted in learning 5 of 7 cardiac-related objectives (at least 80% agree on all 5). 50% agreement and nearly 30% unsure responses on the other 2 objectives indicate a split reaction. Not shown are the results of questions with deliberate unrelated objectives, where the majority of students selected unsure as their response.

Ease of Access and Usability (Table 4). An overwhelming majority of students (over 82% in all questions asked) found the simulator not only easy to access, but easy to learn and the instructions easy to follow.

Anecdotal evidence from students and faculty point to successes and places for further development.

Sample student comments from when they were asked to indicate the best feature of the Heart Simulator:

> *"Being able to change the parameter and see the results."*

> *"It was useful in understanding how changes in certain variables (afterload, preload, contractility, etc.) affect the PV Loop."*

> *"Being able to manipulate different aspects of the Loop to see effect. Only problem was that you have to remember that there are the immediate effects on the heart, which the body may attempt to compensate for."*

> *"Instant feedback. Visualization of concept. Repetition increased comfort and familiarity with use of PV Loop to analyze heart function. Include EKGs."*

As seen above, two students could not resist offering suggestions along with their comments.

Comments from the primary faculty member for the course, Dr. Marc Dickstein, also lend their support to the project:

> *"Rather than simply describing important relationships, I could demonstrate them. And rather than simply reading about important principles, students could discover them for themselves. In medicine, we make observations about patients and relate that to what is going on in the body. The simulator allows students to learn in the same way."*

Dr. Dickstein also commented anecdotally on how the questions he receives from students over email regarding cardiac function are more sophisticated through the use of the simulator.

Instead of general questions such as:

> *"I don't understand contractility, HELP!!"*

students who use the Heart Simulator tend to write questions more along these lines:

> *"I was experimenting with contractility on a patient with an increased preload, and I noticed…what should I try next to understand this better?"*

DISCUSSION

The results of the survey suggest students enjoyed using the simulator and felt it aided their learning in many areas. They also found it easy to use. It is more difficult to say whether they actually learned more or more quickly using the simulator since we did not have the ability to separate the course into different user groups or to compare their actual performance on exams with previous years.

Still, the anecdotal evidence from the faculty member gives us some indication that student learning is occurring. In future studies, it might be useful to track student-faculty interaction to learn more from this type of information.

As biomedical science advances, and as the body of knowledge required in professional practice continues to expand, the value of effective educational tools becomes increasingly apparent. Describing important principles to students through the conventional media of textbooks, lectures, and notes is one thing; demonstrating these principles in action, with instruments that immediately show how multiple variables interconnect, is something else entirely. Real-time observation of physiologic processes occurs in teaching-hospital rounds, animal studies, and related laboratory settings, of course, but such opportunities are limited, and actual hands-on experimentation in patients is out of the question for ethical reasons. A realistic digital simulation of body function, on the other hand, removes such constraints. The challenges in designing such a program include making it flexible enough to be useful in augmenting lectures, individual study, and research alike; maintaining the accuracy of the mathematical modeling while allowing live control of parameters; providing immediate feedback to users as they answer exercise questions; and, ideally, distributing it online with no specialized software installation and no technical requirements beyond a basic Web browser.

The need for this type of educational tool may not appear obvious. After all, the methods of physiology instruction used to date have not failed to supply the medical profession with many generations of competent and gifted cardiologists. In advocating the adoption of new digital methods, Drs. Dickstein and Burkhoff do not claim that conventional textbooks, lectures, labs, and rounds are insufficient, or that digital simulators could replace these materials entirely – but they do claim that simulation, used in complement with traditional static materials, adds two valuable components to the teaching/learning process: *the temporal dimension* and the element of *multivariate interactivity*. The Heart Simulator is equivalent to neither the discovery of sliced bread nor the reinvention of the wheel; its developers offer it as a realistic instrument for integrating, amplifying, and focusing knowledge.

REFERENCES

1. Santamore WP. Burkhoff D. Hemodynamic consequences of ventricular interaction as assessed by model analysis. American Journal of Physiology 1991 260 (1 Pt 2): H146-57.
2. Savery, J and Duffy, T. Problem Based Learning: An Instructional Model and Its Constructivist Framework. In Wilson, Brent (Ed.) *Constructivist Learning Environments: Case Studies in Instructional Design*, Englewood Cliffs, NJ: Educational Technology Publications; 1996: p135-148.
3. Critical Concepts Inc., http://www.critcon.com.