
AC 2011-1083: MEDICAL IMAGING TEACHING SOFTWARE AND DYNAMIC ASSESSMENT TRACKING SYSTEM FOR BIOMEDICAL ENGINEERING PROGRAM

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Medical Imaging Teaching Software and Dynamic Assessment Tracking System for Biomedical Engineering Program

Abstract

Medical imaging education is a key training component in BME programs. Medical imaging education involves teaching physics principles, mathematical derivations, engineering implementations for image generation, reconstruction and application. We developed an Internet accessible, medical imaging teaching software and dynamic assessment tracking system for teaching five commonly used imaging modalities. Each imaging modality is delivered by interactive modules. The system is integrated by the open source MySQL database software that manages updating materials and also tracks student's learning gain through various assessments. Instructor gets instant feedback on the topic delivered through his/her lecture when students work on the system. We have applied this teaching/tracking system in small size classes. The results have shown increased learning gains promisingly. We are continuing the development and plan to apply the system to other local institutions for biomedical or other engineering students.

Introduction

Biomedical engineering (BME) education, a part of STEM, has developed as an interdisciplinary engineering training area in the last 30 years. Based on the current ASEE College Profiles¹², BME undergraduate enrollment has become one of the most rapidly growing engineering majors (Figure 1 left panel).

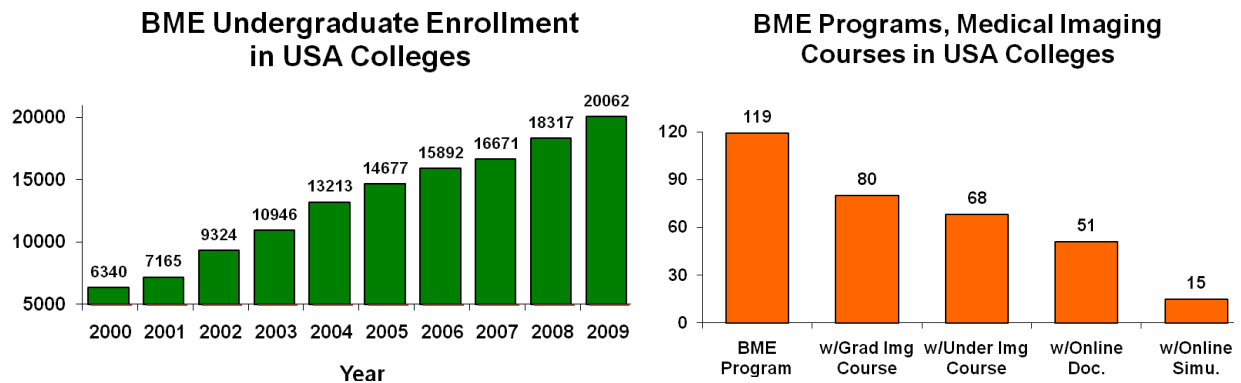


Figure 1 Left panel: BME undergraduate enrollment has been monotonically increasing from 1999 to 2009 and has exceeded 20,000. Right panel: The difference between the number of BME programs and the number of online medical imaging teaching materials indicates a potential development area: Internet-based medical imaging teaching software.

As a key component in BME, medical imaging, combining physics, mathematics, electrical and computer engineering, provides students with a broad view of an integration of different technologies applied to biology and medicine. Recognizing the broad impact of medical imaging education on BME students, many institutions have established such a curriculum. Based on the Whitaker Foundation's BME program database³¹, there are 119 universities or colleges that have BME programs in the nation. 70 undergraduate programs have been accredited by the ABET.

Through the Internet, we surveyed these 119 universities or colleges and found that 80 of them offer graduate level medical imaging courses, and 68 offer undergraduate level medical imaging courses. There are 51 institutions that have Internet-available medical imaging teaching materials; most of them have one or two imaging modalities, and among them 15 institutions have Internet-active (but not interactive) animation or simulation (Figure 1 right panel). Comprehensive discussion for undergraduate medical imaging education has been published³³. We must acknowledge that the survey (in 2009) was based on the Internet available and accessible information and it may not be the most accurate or updated. However, it clearly presents a progressively increasing signal of the BME program and its key component, medical imaging.

Medical imaging involves various physics principles, diverse mathematic derivations for image generation, recognition and reconstruction, special system configurations and specific applications for different modalities. The tremendous amount of information and rapid change in the medical imaging field require teaching material to be more flexible to fit into the available class hours. Efficient teaching for faculty and effective learning for students are crucial to the success of medical imaging education^{20,26}. Along with the progress of other engineering education^{18,27,30}, medical imaging also seeks the best way to deliver knowledge to students. Internet/web-based education (a major subcomponent of the broader term “e-learning”) is one of the tools with which education is popularly delivered^{7,8,16,36}. Education through the Internet makes it possible for more individuals than ever to access knowledge and to learn in new and different ways. Efforts have been made in different aspects, such as image reconstruction techniques varying from the very theoretical^{10,25,38}, to the math-intensive^{11,35}, to algorithm efficiency and to image quality improvement^{1,32}. However, limited efforts actually describe, step-by-step, the process of generation of image data, which is the fundamental education component of medical imaging. Hyper-textbooks are a source of “dynamic” online education that provides additional multimedia elements, as opposed to “text-picture” only textbooks. Several hyper-books^{5,19} are popularly used for medical imaging courses. Most hyper-textbooks provide a “one-way” active teaching model without interactivity.

Interactivity among instructor, teaching material and students is a proven effective way to improve teaching efficiency^{3,4,17}. Interactive learning environments can provide multiple means of representation and expression for the learner through text and graphic modes, animated simulations and other combinations of the media. Interactive education aids in increasing the student’s comprehension, motivation level and perception of learning⁶. Interactive modules allow students to tailor presentations to suit their own exact needs with sound, animation and video capturing the viewer’s attention and conveying explanations more effectively²⁸. Interactive medical imaging education has primarily been for medical professionals^{29,37}, or for developing programming skills for radiologists^{2,14}. On the other hand, the Internet’s interactive feature is usually utilized well but its advantage to learning evaluation is often neglected. For example, the Internet provides the teaching-learning process an efficient and automatic means to receive unbiased feedback by designed assessment functions^{22,34}. A dynamic tracking system embedded in the Internet accessible interactivity teaching software is highly desirable to use the Internet’s unbiased and online feedback feature to influence evaluation.

Pedagogical Motivation

The motivation to start this project was originated from the idea, “A picture is worth/better than a thousand words”, i.e., using pictorial description would be superior to the text-only description. We extended the idea, “A moving picture is better than a static picture,” (by using Adobe Flash Player or Media Player). Furthermore, we added, “An interactive moving picture is better than a simple moving picture,” (by adding interactivities). Ultimately, our goal is to build an online user-interactive teaching/learning system, featuring animation and simulation for physical principles, mathematical derivations and engineering implementations, so as to fulfill the medical imaging education tasks optimally. By this design principle, we try to match student’s learning style¹³, “I hear and I forget, I see and I remember, I do and I understand.”

Design

To achieve the goal of efficient teaching and effective learning for medical imaging, we have developed an Internet based, interactive teaching system, entitled “Medical Imaging Teaching Software (MITS) and Dynamic Assessment Tracking System (DATS)”. The MITS/DATS package provides materials that are parallel to textbooks for teaching five commonly used medical imaging modalities (X-ray, CT, MRI, PET and Ultrasound). Each imaging modality is taught or learned through several “modules” (topics). Figure 2 below illustrates the configuration of this system. Teaching or learning proceeds on the module basis. The system is integrated by the open source MySQL database software that manages updating teaching materials and also tracks student’s learning gain through different assessments. Instructor gets instant feedback on the topic delivered through his/her lecture when students work on the system.

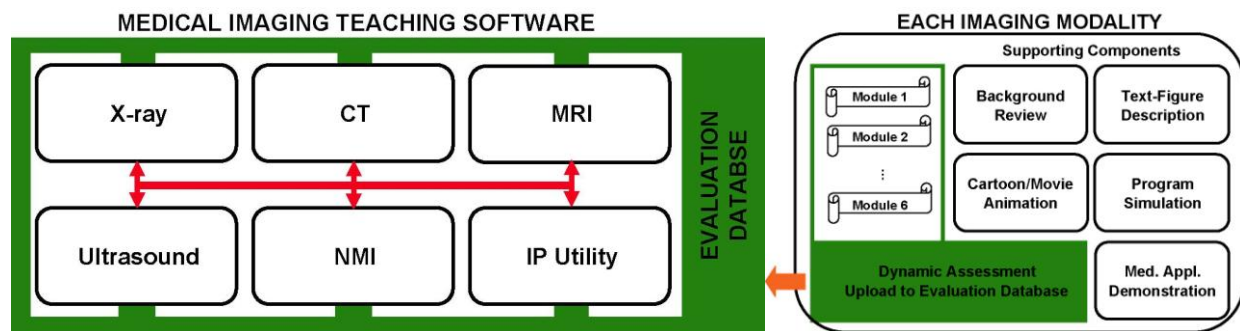


Figure 2 The “hierarchy” of the medical imaging teaching software (MITS) is constructed by Imaging Modalities (level 1, left panel), i.e., imaging techniques (X-ray, CT, MRI, Nuclear Medicine Imaging (NMI), Ultrasound, Image Processing (IP)), Modules (level 2, right panel), i.e., the teaching or learning topics within a modality, and Supporting Components (level 3, right panel), i.e., the methods to deliver a module. These supporting components include Background Review, Text/Figure Description, Cartoon/Movie Animation, Program Simulation, Application Demonstration, and Dynamic Assessment.

Our effort has been focused on the development of animations for physics/chemistry principles and simulations for engineering implementations. We select some components from X-ray or CT imaging modality as examples to describe how the system works.

Background Review contains reviews of related physics and math background (such as modern physics for X-ray, Fourier transform for CT) and historical review of the modality’s evolution (such as radiation’s discovery, evolution of CT’s generations). Our class teaching experience and

other reports²³ indicate that students' learning interest is very much stimulated by the stories of scientific discoveries and inventions. Links to websites relating to the scientists or scientific inventions (such as the "Virtual Nobel e-Museum"²⁴) are also included in this component. Cartoon/Movie Animation provides students an interactive environment to *visualize* a "dynamic" physical process or a "live" instrument (by Adobe Flash Player, Windows Media Player, or even MS Power Point Presentation). Figure 3 below shows X-ray's generation by animation.

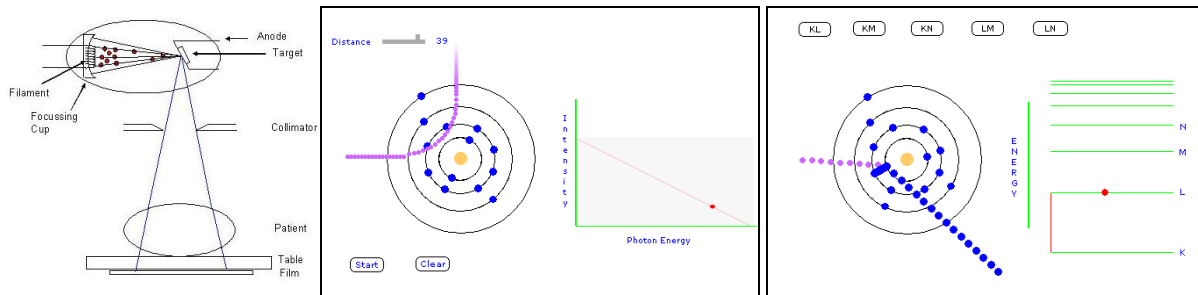


Figure 3 Left panel: An illustrative X-ray tube. Middle panel: The "general radiation" animation lets user change the electron's distance to the nucleus (on the top left corner of the middle panel) and displays the output X-ray energy level. When a user clicks the *Start* button, he/she can see a *flying particle* (animating an electron) *pass around* the nucleus with a changed direction; and the extra energy emitted (i.e., X-ray) is marked on the right side (a continuous function). Right panel: The "characteristic" radiation animation shows user how the radiation relates the nucleus' electron binding energy. When a user clicks the *KL* button, he/she can see a "physical reaction" sequence in which a *flying particle knocks out* an electron in the K-shell (the most inner shell in the figure) of the atom; then an electron in the L-shell (the shell next to the K-shell) replaces the vacancy in the K shell; and the output X-ray energy is shown by an energy transition on the right side (a discrete function). The purpose of an animation is to generate a dynamic "picture" for a physics (chemistry or biology) concept or principle.

Program Simulation is the core training for each modality. Different from animation, simulation is the engineering component of teaching/learning process. A system parameter, such as sampling frequency, processing tools, such as student-designed filter, and images (as original data to be simulated) can be interactively entered (or uploaded) to the system and a computational simulation can be executed and the results can be viewed through the Internet.

Medical Application is a library that posts a variety of medical imaging applications for the corresponding modality. For instance of MRI modality, this component displays MRI images (with brief descriptions) of different part of the body, organs, in normal or abnormal conditions, under different acquisition/processed parameters (such as T1-, T2-weighted, or ADC, DTI maps).

In addition to the above described supporting components for each teaching/learning module, we have also built a dynamic assessment tracking system (DATS), which serves as an online evaluation toolbox. This component is part of the evaluation database ("parallel" to each imaging modality in Figure 2) and also runs interactively. It provides instructor a dynamic teaching assessment tool and student a self-testing function. Figure 4 below illustrates the configuration of DATS, where green blocks are medical imaging modalities described above, while orange blocks are the dynamic tracking system organized by the MySQL database. The assessments include

required information about the engagement, performance (pre/post test), or open-end feedback during the teaching/learning for the modality (on a module-basis or modality basis).

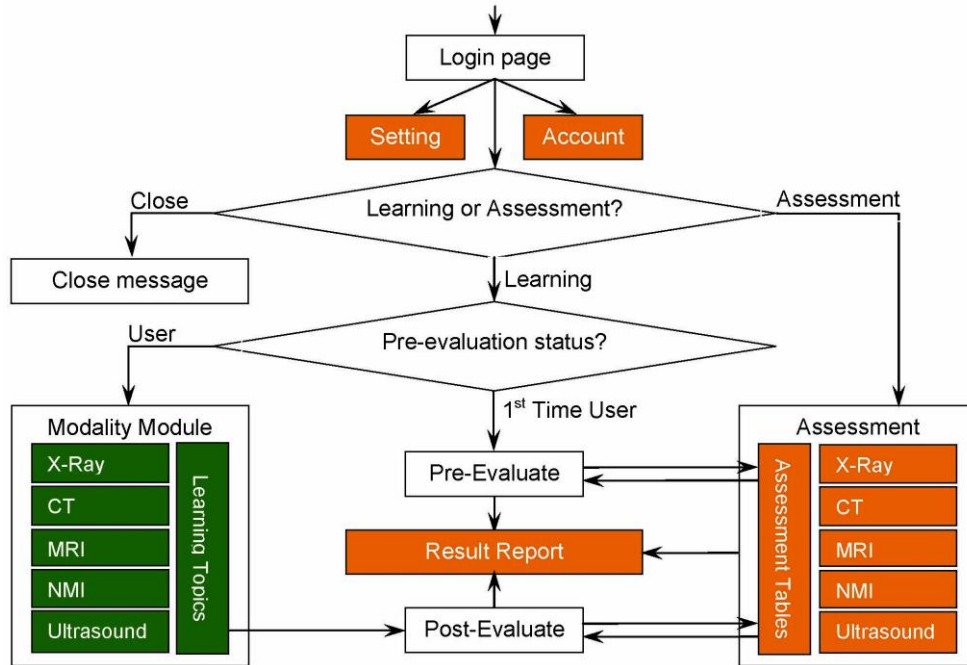


Figure 4 The dynamic assessment tracking system (DATS) enables Independent Administrator Control. The system allows new instructors to join the system from the same or different institutions as site administrators. This system is username/password protected and Internet accessible. The assessment of student performance can be acquired by instructor through the online database.

Implementation

We have applied this teaching/tracking system in small size classes on selected imaging modalities in last few years. The assessment results (pre/post in two different semesters) show impressive learning gains. The learning gains are especially significant in concept understanding. The table below shows results of students learning X-ray and computed tomography (CT) from a medical imaging course (course title: Medical Imaging Systems). All modules associated with the X-ray and CT modalities were issued to students as assignments during semester. Students who enrolled the class were senior undergraduates (60-70%) or graduate students. Students' academic, and course performance records (mean±SD) of without (n=23, top row) and with (n=21, bottom row) are listed in table below:

	GPA	All Prob.	Concept Prob.	Projects
Traditional, without MITS	3.42±0.34	82±9%	76±5%	82±5%
Traditional, with MITS	* ¹ 3.46±0.44	* ² 89±8%	* ³ 91±6%	* ³ 90±6%

where problems (“Prob.” in the table) in the tests and exams were “standardized” questions from the medical imaging review book²¹ and other reference books^{1,9}. Projects for X-ray and CT simulations were the same for both semesters. Statistical comparison (ANOVA, Single factor) of students' cumulative GPA shows no difference between two years (*¹p≤0.7), indicating similar

background of students in two semester. This comparison was conducted to confirm that if any improvement occurred from the application of MITS was NOT caused by students' background difference. Statistical comparison of students' correct percent rate for all questions ("All Prob.") shows no significant difference; however, the low p-value ($*^2p \leq 0.1$) implies a "trend" of increased understanding to all questions (conceptual and computational). Students' understanding improved most in conceptual questions ("Concept Prob.") and in their projects. Both statistical comparisons show significant differences (both $*^3p \leq 0.05$) between two semesters.

Associating with the application of the MITS/DATS system in course-work, we also conducted a test to examine student's understanding on imaging principles through the system directly. We did a preliminary calculation of students' learning gain by the normalized equation^{15,17}, $LG = (post-pre)/(100-pre)$. We found that the average students learning gain ($n=15$) on 17 basic medical imaging concepts was 0.38 ± 0.18 (Figure 5). We must admit that the small number of samples may bring error to the comparisons in some degree.

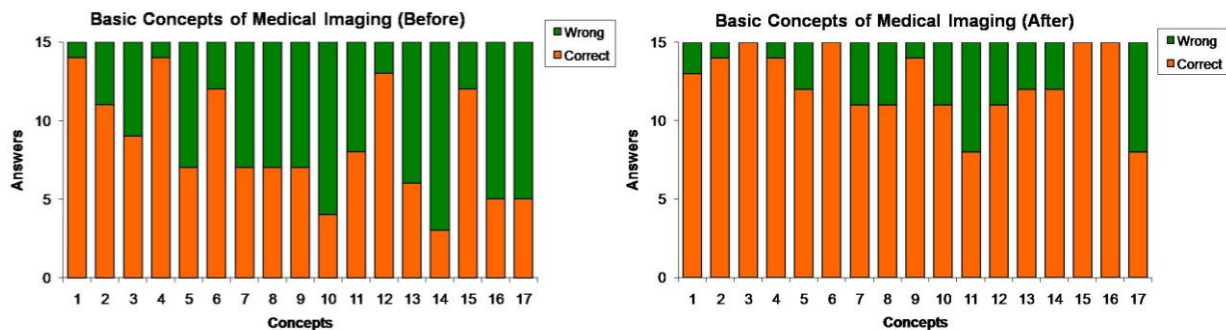


Figure 5 Online assessment of students' understanding on 17 concepts. A concept problem was given before a student started a module and the same or a similar concept problem was given immediately after the student finished the module. Students were informed to finish the module in one logon session so that the pre/post tests reflect the gain through the module only, regardless of students' knowledge from other sources.

Conclusion and Discussion

Based on the outcomes and the evaluations of different assessments, we conclude that the developed MITS/DATS system is convincingly suitable and applicable for medical imaging education to undergraduates. We feel confident to scale up the development through the efforts by multi-institutions to produce a professional medical imaging teaching product that can be adopted by interested academic institutions. In fact, three local institutions are working with us to develop a complete set of animation or simulation components for all five commonly used medical imaging modalities. We plan to distribute the updated MITS/DATS system to institutions that are interested in delivering medical imaging education through this approach. In order to let the medical imaging education community to use the system, two major challenges must be considered, i.e., the hardware and the software.

The hardware means the future "accessibility" beyond the funding cycle. The MITS/DATS system is installed on our local server. We maintain the hardware during the development. However, who will maintain the server after the funding cycle? Our solution is as follows.

Instead of being a “central server” system, the MITS/DATS system is a “portable server” system. The current system is installed on a Dell computer (Model: PowerEdge T310, 8GB memory, two 500GB hard drive RAID). The MySQL database is open source software. The total cost for the hardware is less than \$1500. An institution that will adopt the system only needs the limited initial investment and a static IP for its application. Our Lab will be happy to build such a system and install the current version of the MITS/DATS and the MySQL database on the server for other institutions.

The software means the future “sustainability” beyond the funding cycle. Establishing an online teaching system is a “one-time” effort (we acknowledge that it is a time-consuming effort). However, the system must be sustainable beyond the funding cycle. A “live” teaching system must be an upgradeable (continuous-optimizing) system. Our solution is as follows. During teaching a specific module of an imaging modality, we assign students or recruited interns a project that requires students to create an animation or simulation for a specified physical/math/engineering concept. In the end of the semester or internship, each student presents his/her work to the class or other interns. The instructor asks all students to which animation/simulation gives the most thorough overview of the specified concept. Students then “evaluate” all presentations (including existing work) and “vote” for their favorite animation/simulation. The best animation/simulation will replace the existing one for this concept. By implementing such a method, the MITS/DATS system will not only be sustainable but also upgradeable. At the same time, both hardware and software will be controlled by the institution locally.

We plan to hold an annual medical imaging education forum among institutions that use the MITS/DATS system to exchange application experiences under difference training environments, such as large class size, community college, other engineering or medical students, and to synchronize the system adaptively.

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