AC 2011-2001: A COMPARATIVE STUDY OF CLASSROOM LEARNING AND ONLINE LEARNING ON MEDICAL IMAGING WITH COMPUTER LAB EXERCISES

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A Comparative Study of Classroom Learning and Online Learning on Medical Imaging with Computer Lab Exercises

Abstract

In this paper we present a study on the effectiveness of using a computer simulation software, SimuRad, in lab exercises for an undergraduate Medical Imaging course. This course is offered regularly in two modes, i.e. an on-campus section and an on-line section in different semesters. This enables us to compare students' learning experience with the same software in different environment. Our initial findings suggest that there is no significant difference in the effectiveness of these computer labs between the two groups of students. However, some slight but interesting differences in students learning behaviors are also observed. The development and assessment of this software is partially supported by an NSF CCLI grant.

Introduction

“Medical Imaging” is an important subject in most bio-medical and bio-engineering curricula. It is a multi-discipline subject involves studies in biology, physics, mathematics, electrical engineering, and computer science. A comprehensive medical imaging course may cover fundamental science and engineering principles (e.g. atomic and nuclear physics, Fourier analysis and reconstruction, and computer assisted tomography), medical imaging modalities (e.g. x-ray radiography, x-ray CT, nuclear medicine gamma imaging, magnetic resonance imaging, and ultrasound imaging), and clinical imaging practices (e.g. image analysis, visualization, instrumentation, and radiological protection). Although it has been a typically a graduate level course in most of the radiology, medical physics, biomedical engineering, and computer engineering programs, it has also been frequently offered to undergraduate students as a required or elective course.

In order to offer this as an introductory undergraduate course, it is necessary to emphasize conceptual learning through lab exercises. We have designed a series of computer lab exercises based on a newly developed computer simulation software – SimuRad, which can help students better understand the underlying science and engineering principles of medical imaging. SimuRad is an interactive software which implements numerical algorithms to simulate physical and biological processes in most common medical imaging modalities. The software contains expandable modules, each to support a serious lab exercises related to a particular modality. Currently implemented modules include math fundamentals, computed tomography (CT), x-ray physics, nuclear magnetic resonance (NMR), image enhancement and analysis. With these modules, seven computer lab exercises have been designed.

Medical Imaging is a required course in the undergraduate Bio-Medical Engineering (BME) program at Stevens Institute of Technology. This course is offered each year in Fall semester as a regular on-campus course, and in Spring semester as an on-line course. We started the deployment and assessment of these lab exercises in Fall 2008, and by Fall 2010 we have obtained the assessment results for more than two consecutive years. These results enable us to study student learning behaviors and performance in many different ways. In particular, we attempt to have a comparative study on students' learning experience in these computer-based lab
exercises during the regular on campus sections (F08, F09 and F10) and during asynchronous online sections (S09 and S10).

Our assessment of students' learning experience is currently based on student surveys. We designed a simple set of survey questions for students to complete after each lab exercise. The survey was voluntary. The questions include the scales of student's understand of a certain concept before and after the lab exercise, the scale of knowledge preparation for the lab exercise, the time spent on the lab exercise, and the need for lab design improvement. Following is an example of survey instruction provided in a lab assignment.

Answer the following survey questions using the scale 1 ~ 5 (1: strongly disagree, 5: strongly agree):

1. You understand the concept of "filtered back projection method" BEFORE you take this lab exercise. 1 2 3 4 5
2. You understand the concept of "filtered back projection method" AFTER you take this lab exercise. 1 2 3 4 5
3. You have the knowledge and skill to complete this lab exercise without additional study beyond the lectures. 1 2 3 4 5
4. This lab exercise takes you too much time. 1 2 3 4 5
5. You think a better lab exercise can be designed to reach the objectives of this lab exercise. 1 2 3 4 5

We have the following considerations in analyzing the survey results:

- The difference between the Q1 score and the Q2 score roughly represents the student's perceived performance improvement.
- The Q4 score, normalized by the Q3 score, roughly indicates the difficulty level of a particular lab.
- The Q5 score indicates the need to improve the usability of the lab.

Accordingly we extract three metrics for assessment purposes:

- perceived performance improvement (PPI) = Q2_score - Q1_score,
- normalized improvement index (NII) = PPI/Q1_score,
- normalized difficulty index (NDI) = Q4_score/Q3_score.

Every year the Medical Imaging course is offered on campus in the Fall semester, and online in the Spring semester. In the on campus sections, the course constitutes a 1.5-hour lecture and a 2-hour lab time. In the online sections, students are advised to spend the same amount of time for reading lecture notes and taking lab exercises. Students typically took 9 to 10 weeks to complete all seven labs, as described in the following section. Upon completion of each lab exercise, students are required to write a lab report. The contents of the lab exercises, e.g. procedures and results, were included in the midterm and final exams. We typically had around 30 students
enrolled in the Fall semester and around 30 students in the Spring semester. The students are from the same student body, and mostly of them are our on-campus undergraduate BME students. The reason they take the course in different semester was mostly because of scheduling issues.

We have collected the survey results from the Fall 2008, Spring 2009, Fall 2009, Spring 2010 and Fall 2010 semesters. The response rates vary from 50% to 75%. The overall average survey scores for each lab and in each semester are shown in Figure 1~7. The results are grouped into on-campus sections (F08, F09 and F10) and on-line sections (S09 and S10) for each lab.

**Descriptions of the Lab Exercises and Assessment Results**

**Lab 1. Convolution and Fourier Transform (math preparation)**

Student generates different signals by selecting multiple simple waveforms, e.g. sine, square. The amplitude, frequency and phase of each simple waveform are specified by the student. Then Fourier Transform is performed and the frequency response is displayed for each generated signal. Student is instructed to try a sequence of parameter sets to observe the changes of frequency responses corresponding to changes in signals. Student then selects a filter. Convolution of a signal with the filter is implemented through multiplication in frequency domain, which is to demonstrate the concept that filtering is a process of frequency selective attenuation or amplification.

![Figure 1. Lab 1 survey and assessment results.](image)
Lab2. Projection and Projection Slice Theorem (tomography)

Student first creates simple 2D objects from isolated points, simple shapes (rectangle, circle, ellipse etc.), and observes their projection (radon) domain presentations. The number and angle of projections are specified by the student. A phantom template is also provided so that student can manipulate the components to created different phantom objects for projection tests. Student then use the phantom object to validate projection slice theorem. The process is to take one projection at student specified angle, then display this projection signal, the 1D FFT of this projection, as well as the corresponding slice of the 2D DFT of the phantom image. The student can observe the consistence of these two FFT results at any selected projection angle.

![Lab 2 On-Campus Section Survey](image1)

![Lab 2 On-Line Section Survey](image2)

![Lab 2 On-Campus Section Assessment](image3)

![Lab 2 On-Line Section Assessment](image4)

Figure 2. Lab 2 survey and assessment results.

Lab 3. Frequency domain reconstruction – number of projects, interpolation methods (x-ray CT, MRI)

Student selects a 2D object and specifies the number of projections, number of samples per projection and projection angles. The projection results are displayed. Each projection is then placed on a 2D frequency domain at corresponding angle, and this process is displayed in both 2D and 3D plots. After all projections are placed into this 2D space, interpolation is performed to create samples at Cartesian grid, and a 2D inverse FFT is performed to generate the reconstruction image. Student is instructed to try a sequence of parameter sets to observe the changes in reconstruction image quality. In particular, frequency domain interpolation can only be observed clearly when number of projections and number of samples per projection are small,
but good quality image can only be obtained when these numbers are large. Student will explore these different settings and report the findings.

![Lab 3 On-Campus Section Survey](image1.png) ![Lab 3 On-Line Section Survey](image2.png) ![Lab 3 On-Campus Section Assessment](image3.png) ![Lab 3 On-Line Section Assessment](image4.png)

Figure 3. Lab 3 survey and assessment results.

**Lab 4. Filtered back projection – number of projections, filters, noise (x-ray CT)**

Student selects a 2D object and specifies a projection angle and number of samples per projection. The 1D projection is displayed. Then student clicks "back-projection", and observes the creation of a 2D back-projection image displayed in both 2D and 3D plots. Student then specifies a series of projection angles, and observed the accumulation of all back-projections into one 2D reconstruction image. Student should see that such reconstruction looks blurred and too bright. Student then selects a filter and applies it to each 1D projection before the back-projection. Student will observe a much clearer reconstruction image from filtered back-projections. Student will further explore different filters, cut-off frequencies of filters, and projections with different levels of induced noise. The filtering effects become more evident. Given the large parameter space, this exercise is rather long and it usually takes students two weeks to complete.
Lab 5. X-ray attenuation coefficient and survival probability (x-ray)

Student selects a material from ("adipose", "air", "aluminum", "bone", "copper", "iodine", "lead", "lung", "muscle", "soft tissue", "water"), and changes the incident x-ray energy from 10 to 400 KeV. The mass attenuation coefficient is displayed for each material at each x-ray energy level. Absorption edges for some materials can be observed when the energy increment is small. In the second part, student selects a metal material, an incident x-ray energy and changes the thickness of the material to observe the numbers of survival x-ray photons after the penetration. The results are based on NIST dataset, and there is not much computation involved.
Lab 6. NMR signals – precessions, relaxation, basic sequences (MRI)

Student first gets familiar with 3D vector representation of spin magnetization, by specifying an excitation on the equilibrium vector Mz, and observing the resulting 3D vector. Then student will observe spin dynamics including transverse (T2) relaxation, longitudinal (T1) relaxation, and free precession individually and jointly. Student specifies T1, T2 times, initiates an excitation angle, and then observes the vector changes over time, typically for a range of 1 ~ 2400 ms. The display is progressive for 10 frames per second. At the same time, the student will also observe the FID (free-induced-decay) signal waveform generated from each session. In the second part, student simulates some basic NMR sequences, including saturation recovery (SR) and spin echo (SE). In SR simulation, student specifies the T1, T2 values, an excitation angle, the repetition time (TR), echo time (TE), and repetition number. Student will observe the vector animation and FID that is generated. In SE simulation, student specifies number of spins, e.g. 10, off-resonance frequencies randomly distributed between -50 Hz and 50 Hz. Student can observe the animation of all these spin vectors and the aggregated FID signals. In particular, this simulation is very helpful in explaining the divergence and refocus of magnetization on x-y plan in SE. This exercise is also very long, and it usually takes students two weeks to complete.
Lab 7. Brain activation detection in fMRI (image analysis)

Student is given a functional MRI dataset containing one axial brain slice for 68 time samples. Each image is of 46 by 55 in size. The data was collected by a 1.5T GE Echo Speed Horizon scanner for a finger-tapping test. The paradigm contains 4 on-periods and 5-off periods, which is explained to the student. The first image is displayed, and the student can click any pixel on the image to display the time sequence of that pixel. In the lab instruction, a few active pixels are listed, and student can locate these pixels and see the similarity of these time sequence with the paradigm. Then student is asked to find a few more active pixels, e.g. five. A t-test tool is provided, so student can obtain the t-value for any selected pixel, and can observe that higher t-values correspond to higher similarity between the selected pixel and the paradigm.
Assessment Discussions

Overall we think the results match our expectation well. We see clearly an increase of score from Question 1 to Question 2 in all of the lab exercises across all sections, which indicates improved understanding of topics under investigation. From Question 3~5 results we see that most of the students seem satisfied with the implementation and usability of the software, although complains of "too much time spent" can be observed from Question 4 results, especially in Lab 3 and 6. It should be noted that some results from Fall 2008 were not quite consistent with others. This is partially because that it was the first time the assessment was introduced, and the response rate was quite low.

More specifically, from the results we have the following observations:

1. The perceived performance improvement (PPI) scores are positive and significant across all labs for all semesters, which indicates the general success of our software based labs.

2. Overall the PPI and NII scores are quite close between on-campus sections and on-line sections, which suggests that the software labs can provide comparable learning experience to both student groups. This is a significant finding to support such tools for on-line learning.

3. In the first three labs, there is a clear indication that the software is more effective in helping those online students than the regular on-campus students. This may be explained as the fact that online students are more relying on the tools to understand the concepts, while on campus students may depend on instructor in the lectures. The phenomenon appears clear at the beginning of the course, but eventually disappears in later part of the course. One possible reason is that, when the course progresses, students become more alert to new knowledge they learnt.

4. When the difficulty level (NDI) of the lab exercise is high, as seen in Lab 6 (NMR), on-campus students may learn slightly better than the on-line students, which needs to be further confirmed. Lab 6 is generally considered by students as much more difficult than other labs. Students' behavior in this lab is worth careful study.

5. Lab 7 has relatively low NDIs and high PPIs across all semesters. This may have an interesting implication, i.e. students tend to learn better with simple but application-oriented exercises. In this scenario, on-line students appear to be more satisfied.

In many cases it is very difficult to make conclusive statement given the current survey data. We will continue our studies in the following years. We will also try to introduce direct assessment metrics for each lab exercises. The plan is to design some homework and exam questions, and correlate students' grades with their survey responses. Given our unique advantage of having two sections of the same course, one on campus and one online, we believe that our continuous comparative study will produce helpful findings to the entire online learning community.
Conclusion

We designed a series of computer lab exercises using SimuRad for an undergraduate medical imaging course, which is regularly offered both on-campus and on-line. Assessments on these labs were obtained through student surveys. We studied the assessment results and obtained some interesting findings. The results generally indicate that this software is a helpful learning tool and its usability is satisfactory. We also observed that students' learning behaviors are slightly different in some instances between the on-campus sections and the on-line sections. We believe that some observations call for further investigations, which may provide insights for developing more effective learning tools, especially for online learning.

Bibliography