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Creating New Labs for an Existing Required Biomedical Engineering Imaging Course

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Abstract

In an effort to increase hands on learning in the biomedical engineering curriculum, laboratory components have been added to many core courses at XXXX University. One such course is BME XXX: Modern Diagnostic Imaging Systems. Taught for (junior and/or senior) students, this course has an enrollment of 70-80 students each year. The learning objectives of the laboratory modules were to 1) give students a sense of how the equipment works in a real life setting; 2) incorporate elements of creativity and design; 3) improve student performance; 4) increase student interest in the subject material; and 5) give the students the opportunity to learn tangible skills that are applicable in the industry.

Throughout the course of the semester, the students experienced a combination of design challenges, lab experiences, and clinical experiences based on the section of the course they were completing. The course had 6 sections, 5 of which had laboratories/experiences associated with them. For the first experience, students developed and printed a 3D imaging phantom to use in all subsequent imaging modalities. This required students to familiarize themselves with Fusion360 and the 3D printers, which satisfied both learning objectives 1 and 5. During the Xray section of the course, the students brought their phantoms to a research imaging facility where they were able to create Xray images and CT images of their phantoms. For the CT portion of the course, students used visible light and simple backprojection to reconstruct a wooden block. For the ultrasound unit, students arrived in the lab to their phantoms obscured by milk and had to use the ultrasound images to identify which phantom was which. For the MRI unit, students traveled to a clinically operating 3T magnet at XXXX hospital and watched while their phantoms were scanned. As an extra credit assignment, students were asked to identify which phantoms had been scanned.

The same final exam was administered at the end of the course during semesters with and without the laboratory component. Note that the lecture content of the courses did not change. For the spring 2016 class with no laboratory component, the final exam score was 78.1+/- 11.8 (mean +/- stdev). For the spring 2017 class, the final exam score was 84.6+/-8.3 (mean +/- stdev). Using a t-test, there was a statistically significant difference found ($P<.003$). Incorporating these hand-on design and image evaluation activities into the class significantly improved student mastery of the course content. As described, the laboratory modules also met the other learning outcomes for the laboratory.

Overview of Prior Modern Diagnostic Imaging Course

BME XXX: Modern Diagnostic Imaging has been taught at XXXX University for over 20 years. Seven years ago, this course became one of four area core courses (called "cores") for the BME major, typically taken during junior spring. Junior students majoring in BME are required to select two of the four area cores that are only offered in the spring. Prior to this curriculum change, the course was largely comprised of graduate students and considered an elective for undergraduates.

BME XXX was largely a theoretical course that covered the imaging physics of most of the major imaging modalities currently on the market: Xray, CT, Single Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET), ultrasound, and MRI. Each topic was given roughly two weeks or four lectures to explain the imaging physics behind the modality and each topic had a separate homework assignment to allow the students to demonstrate mastery of the material.

The main complaints about the course over the years was that it was too theoretical. Specifically, students complained that they weren't able to see the equipment they were learning about or try out the imaging modalities for themselves. In addition, other faculty had expressed dismay that the course did not have laboratory modules, and thus the course was viewed as being "easy" in comparison to the other four cores, two of which have extensive wet labs.

Below are some examples of feedback from students from the lecture-only course:

- "It was an alright class but the tests had not much to do with the material and just the equations in the course which I think could have been changed."
- "The actual content of the class is extremely interesting. However the material isn't particularly taught well and since it's a lecture only with no recitation or lab there's no other way to learn the material or reinforce what you learn."
- "The course had excellent material, but it would have been cool to see the technology in real life."

In summary, the feedback was that the course material was dense, complex, and hard to understand. The common theme from reading our evaluations was that the course was too theoretical and was missing the hands on component that a laboratory experience would bring.

Motivation for the Addition of Laboratory Modules

Experiential learning through laboratory work has long been shown to be key to student retention and connection of information. To enhance student learning, many esteemed educators have recommended connecting the material being taught to an "experience"[1]. These experiences allow them to uncover conceptual deficiencies in their own thinking and overall lead to a deeper understanding of the course content.[2,3] Laboratory modules are the connection between the theory of the science and the practice of it.[4] Our goal for this class is to give students an understanding of the imaging physics behind the 6 imaging modalities that are covered in class by incorporating experiences that allow the students to interact with the imaging modalities being taught. We believe incorporating this element is crucially important for their retention of information. The learning pyramid[5] shows that incorporating hands on/practiced based activities significantly improves retention of the material[6]. When students use the imaging tools themselves they get a deeper understanding of how it works and are more able to connect the information they learn in lecture to the actual device they experience in the laboratories.

Adding a series of laboratory modules was seen as a way to integrate the material and form a more resilient conceptual framework from which to understand all of the imaging modalities students would encounter in the course. In addition, there was significant discussion by the departmental faculty of incorporating tangible skills into classes, requiring courses to build on one another, and incorporating design throughout the curriculum.

With the curriculum adjustment, a much larger percentage of the class was undergraduates, and the class size increased precipitously, which both reduced the one-on-one time possible with each student and changed the overall level of student interest in the topic. Prior to spring of 2011, the course was less than 20 students comprised almost exclusively of Ph.D. students who were studying medical imaging systems. With the curriculum change, the course had to accommodate double the number of students that had less overall knowledge and interest in the material.

Development of the Laboratory Modules

The five learning objectives of the lab experiences were:
1) Give students a sense of how the equipment works in a real life setting.
2) Incorporate elements of creativity and design.
3) Improve student performance.
4) Increase student interest in the subject material.
5) Give the students the opportunity to learn tangible skills that are applicable in the industry.

The course was enhanced with laboratories for the 2016-2017 academic year. Forty-seven students enrolled in BME XXX for spring 2017. In anticipation of adding laboratories to BME XXX, the BME department used laboratory funds to purchase five ultrasound scanners from Interson[7]. Labs occurred approximately once a month with the exception of the CT module which had a lab two times a month. The deliverables were different for each laboratory and are detailed below.

Lab 1: The first laboratory project was to develop and 3D print an imaging phantom that met certain specifications. Each student made a 3D model of a cup, which was the base of the phantom. The students added features to the bottom of the cup that were to test the resolution of the various imaging systems in the x, y, and z direction. The students were responsible for both creating their 3D phantom in the 3D modeling software of their choice and printing it. In addition, the students had to include their highest and lowest resolution tested in the x, y, and z directions. With this design, the students could use inherent contrast in the imaging phantom in all subsequent imaging modalities in the class. As described below, the phantoms were tested in four imaging modalities; This comprises Labs 2, 4, and 5. A photo of one of the resolution phantoms is seen in Figure 1.

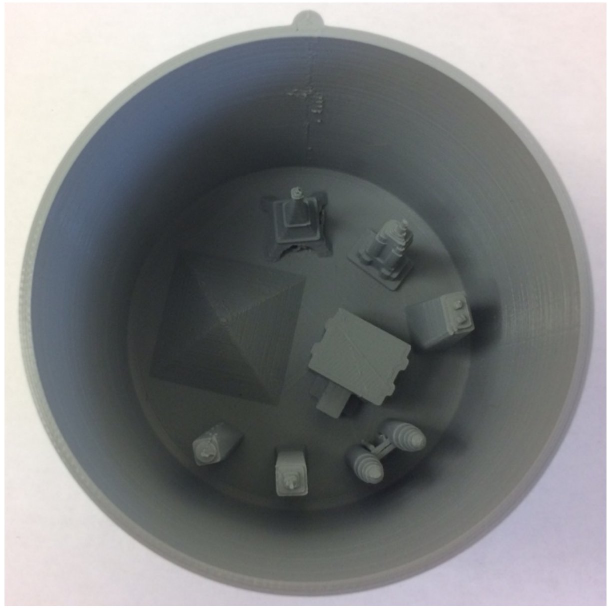

Figure 1: Example 3D printed Resolution Phantom

Lab 1 addresses learning objectives 1, 2, and 5 by having students use 3D modeling CAD software such as Fusion 360, SolidWorks and Inventor. In addition, building a resolution phantom allowed them to apply their knowledge of point spread functions and concepts from lecture into their actual design, addressing learning objective 4. Students then were allowed to vote on their favorite resolution phantoms in class with 5 specific categories: Widest range of resolution; Most creative; Finest resolution; Best overall test of resolution; And best overall design. The 5 selected phantoms were then used in the ultrasound laboratory and the top student selected phantom was scanned with Xray, CT, and MRI.

Lab 2: In this lab, students scanned the class' favorite phantoms in the MicroCT laboratory affiliated with XXXX University, resulting in both an Xray and CT image of their chosen phantoms. The phantoms were taken to a MicroCT laboratory and scanned and the students visited the laboratory while the phantoms were being scanned, getting to see how contrast in Xray could be altered and watching the CT reconstruction process as well as several videos of the phantoms. This particular assignment addressed learning objective 1 for the course. A CT and Xray image of one of the 3D printed phantoms is shown in Figure 2. This laboratory had no deliverables other than attendance was required.

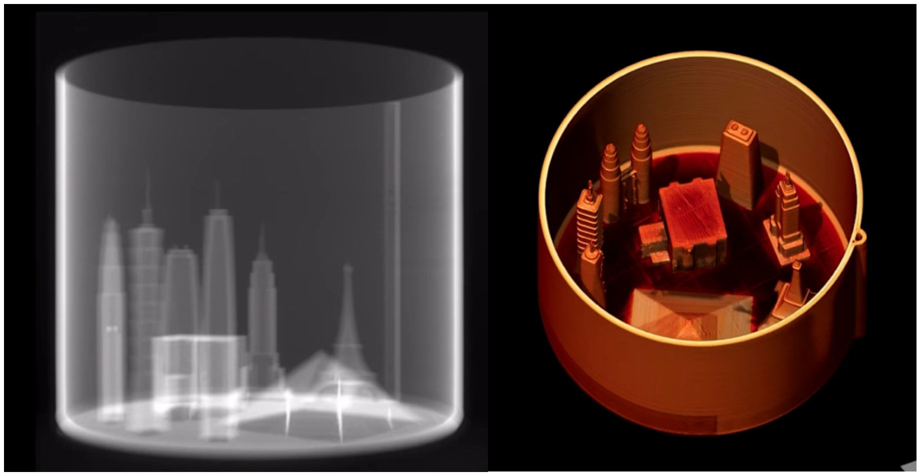

Figure 2: Xray and CT of the student-made resolution phantom seen in Figure 1, respectively

Lab 3: Lab 3 was an in class hands on demonstration of CT back projection reconstruction using wooden blocks and flashlights. All students were given flashlights, a wooden block of varying shapes and sizes, and a paper with an enormous circle that served as the student's makeshift CT "scanner" which they used to perform a crude visible light CT back projection of their wooden block. This allowed the students to take something that was abstract and mathematical (back projection reconstruction) and connect it to something tangible that they could perform in 5-10 minutes, addressing learning objective 3 and 4. An example of the setup the students used is seen in Figure 3 below.

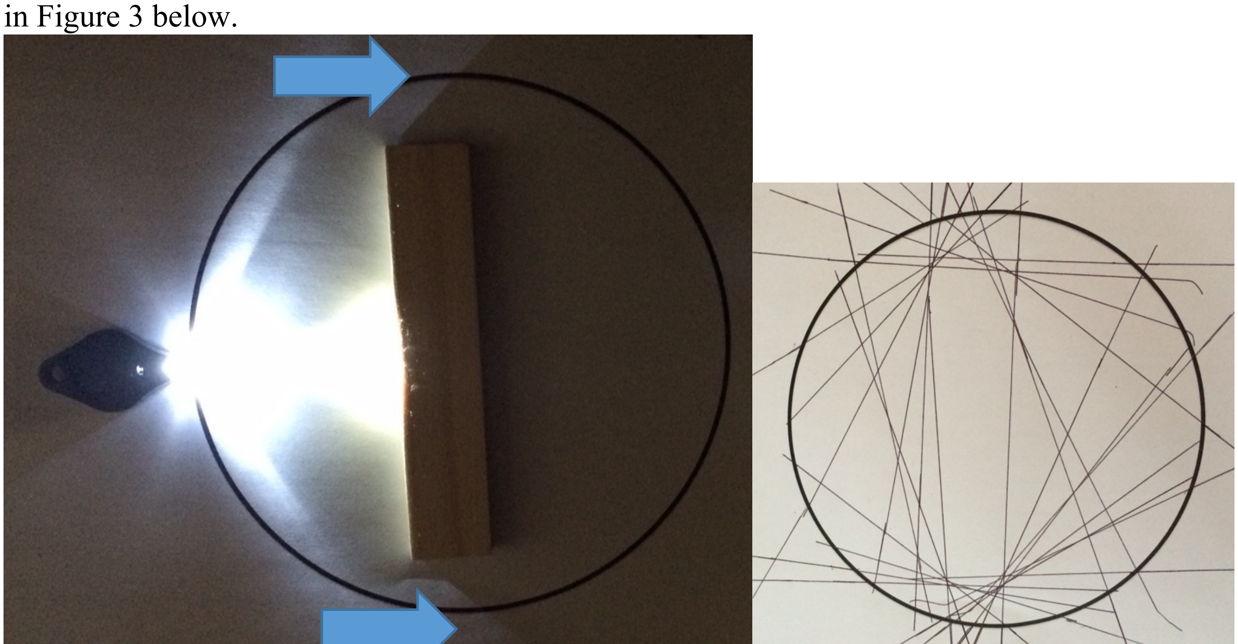

Figure 3: CT Experiment setup for students (left). Blue arrows indicate where lines would be drawn for one "projection". Students then rotate the light slightly and drawn the next projection until they have "enough" projections to reconstruct the image as seen on right with crude approximation of CT backprojection.

The setup for the experiment was performed in class, and a crude drawing was created, but students were required to take the items home and perform a more carefully crafted reconstruction. Students turned in the completed back projection reconstruction as part of a homework assignment seen in Figure 3 (right) for the block in at least 2 different positions. The block shown in Figure 3 could be rotated on its side to create a different back projection image with different locations of light reflections. All students turned in their reconstructions, but the students with the best reconstruction received extra credit. The winners from the spring 2018 class are seen in Figure 4 to give an idea of the different shapes the students were able to reconstruct using the technique.

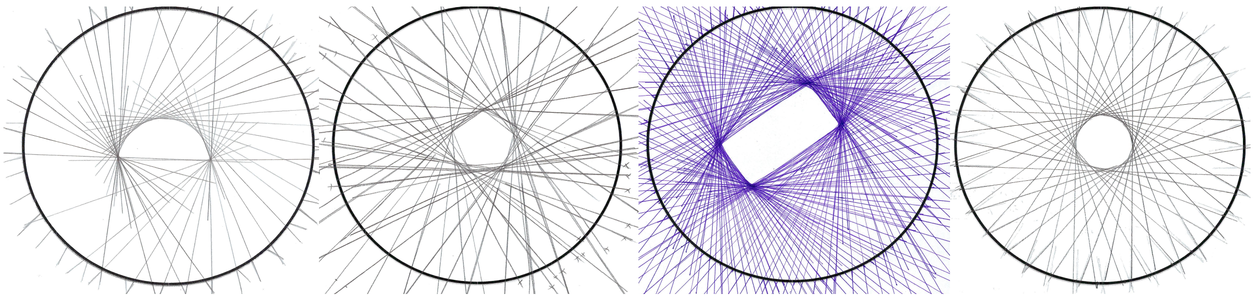

Figure 4: Four examples of backprojection result students submitted for credit for 4 different shapes

Lab 4: The fourth laboratory experience consisted of filling the 5 student-selected resolution phantoms with milk so they could not see inside them and using the ultrasound images created to match each phantom with its ultrasound image. Students had to incorporate understanding of geometry and ultrasound contrast into their ultimate phantom selection, supporting learning objective 1. An example of the image and setup for lab 4 is seen in figure 5.

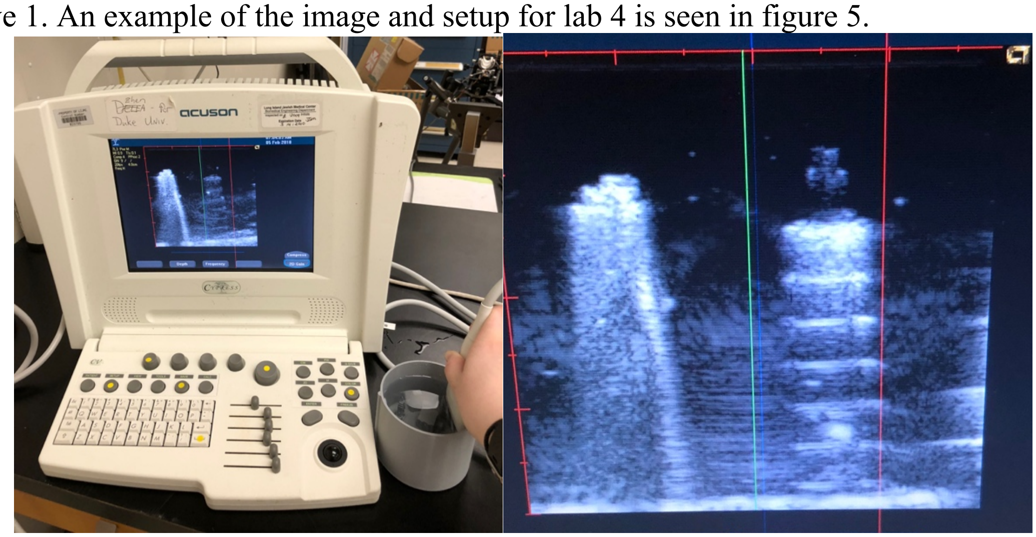

Figure 5: Setup of ultrasound experiment (left) and ultrasound image of the same phantom shown in figure 1 (right)

For lab 4 each student turned in a laboratory report which consisted of short answer response to questions about contrast and resolution that they witnessed in the ultrasound laboratory as well as their laboratory determination matching each phantom with its respective ultrasound image.

Lab 5: The final laboratory experience was an in class viewing of an MRI image of one of the phantoms. Students were able to see how the CT image of the phantom compared to the MRI image, the Xray image, and the ultrasound image. The only imaging modality they were not able to experience was a nuclear medicine scan due to safety concerns about radiation exposure. Students could compare the MRI image with T1, T2, and proton density weighting as seen in Figure 6. This was an observational experience, no deliverables were required.

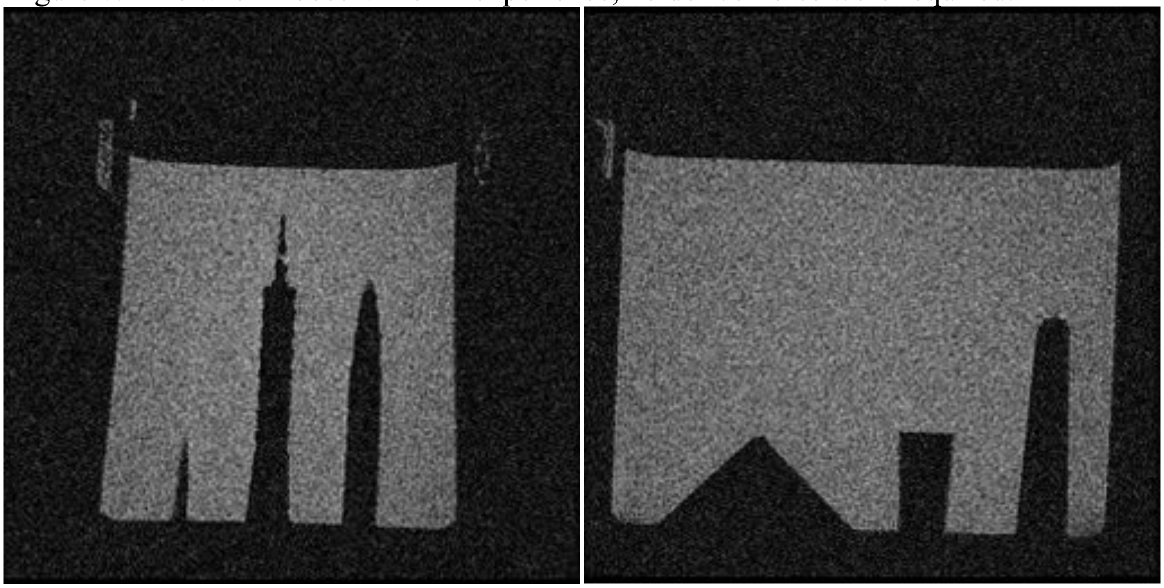

Figure 6: MRI of 3D resolution phantom shown previously for 2 example slices

Assessment of Additional Laboratory Modules

To see if the five laboratory modules had an effect on student performance, the same final exam was given to the students both before the lab was enacted (spring 2016) and after the described labs were incorporated (spring 2017). The final exam score was 78.1+/- 11.8 (mean +/- stdev) with N=54. For the spring 2017 class, the final exam score was 84.6+/-8.3 (mean +/- stdev) with N=47. Using a t-test, there was a statistically significant difference found ($P<.003$). The final exam was never returned to the students and students were not allowed to have their cell phones during the exam to take pictures of the exam thus making it highly unlikely that the students could share information about the final between years that would result in this significant improvement in scores. Furthermore, the model of reusing final exams has been employed in other BME classes taught by the same professor with roughly the same cohort of students and no such improvement trend has been observed despite using the same final in 4 consecutive classes.

Course evaluation feedback was also considered, though the courses showed no statistically significant changes in instructor quality, course quality, quantity learned, or workload from one year to the next. The course evaluation feedback is reported in Figure 7.

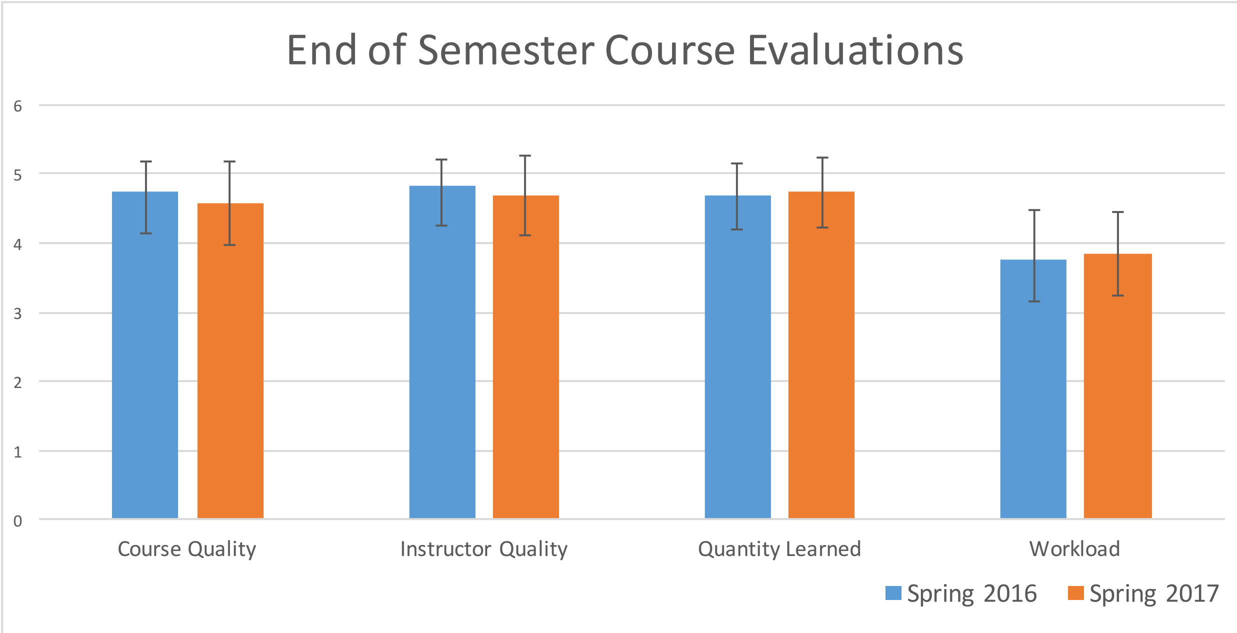

Figure 6: End of semester course evaluations between spring 2016 and spring 2017

In addition to final performance, students offered laboratory feedback on their course evaluation for spring 2017 students. While there were no questions specifically addressing the laboratory components (an oversight which will be corrected this semester), the students, of their own volition, decided to highlight the laboratory experiences as the stand-out feature of the class. Below are excerpts of student comments from spring 2017 course evaluations:

- "Exciting, because all the material that we learn is presented to us in a very unique way, through demonstrations and class projects."
- "I loved the labs and being able to see what I was learning in action."
- "Would have liked even more field trips to see all of the imaging modalities in action and more of a hands on component!"
- "I believe it would be cool to have some sort of real-life experience (SMIF facility, U/S lab) for all the imaging modalities."
- "The introduction of several lab components was greatly appreciated as they helped explore the practical and hand-on aspects of many of the imaging modalities we discussed in class."

As is clear by the comments from the students, these laboratories were well received and augmented the student's understanding of the material. In addition, with the improvement in final exam course scores, it appears that the laboratories have had a net positive effect on the overall learning objectives and goals of the course.

Future Improvement of Laboratory Modules

BME XXX is being taught for the second time in spring 2018 . The laboratories are being iterated and improved from the previous year, based on feedback from the students and faculty. This semester, students have attended a Fusion360 training lab where they had to individually create a resolution phantom before being broken in teams to print their final resolution phantom for submission. Deliverables are being added to all laboratory experiences, unlike the previous incantation which did not have deliverables for lab 2 and 5. Unlike the previous year, where only the top two phantoms were chosen to be scanned at our MicroCT facility due to expense, this year all phantoms will be scanned at our MicroCT laboratory and all of the student teams will be responsible for creating an Xray and CT movie of their resolution phantom incorporating a number of instructor specified features and further augmenting learning objective 1 and 5.

The ultrasound lab will be largely unchanged, students will be presented with their phantoms filled with milk and will be asked to identify phantoms only from their ultrasound images. As an addition, students will complete a pre-survey of their comfort and familiarity with the imaging modality followed by a post survey after the laboratory experience to improve the quantifiable metrics of laboratory success. This year there will also be faculty created phantoms that pose additional geometrical challenges that the students will need to figure out.

Lastly, as a final addition, students will tour a clinical MRI scanner and will view their phantoms using different MR pulse sequences so they can see for themselves how contrast can be altered using MR. These changes should further augment our students understanding of the content of the course and support the learning objectives for incorporating labs.

In addition to improving the laboratories as outlined above, the students will also be surveyed about each lab experience and then a survey of the laboratory experiences overall to hopefully allow for more targeted improvements in the laboratories moving forward.

Conclusions

Five laboratory experiences were incorporated into a previously lecture-only course to achieve the five learning objectives: 1) give students a sense of how the equipment works in a real life setting; 2) incorporate elements of creativity and design; 3) improve student performance; 4) increase student interest in the subject material; and 5) give the students the opportunity to learn tangible skills that are applicable in the industry. Through evaluating both student feedback from course evaluations and by calculating final exam scores, the net effect of the laboratories improved student performance, while not significantly altering student satisfaction with the course. In conclusion, the laboratory exercises designed and implemented at XXXX University have had a net positive effect on the overall course BME XXX: Modern Diagnostic Imaging Systems, while also satisfying the original goals of adding laboratories.

Acknowledgements

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