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A Mixed Learning Approach to Integrating Digital Signal Processing Laboratory Exercises into a Non-Lab Junior Year DSP Course

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ABSTRACT

Laboratory courses can be difficult to fit into an engineering program at a liberal arts-focused university, which requires students to be exposed to appropriate breadth, as well as sufficient depth in their engineering education. One possible solution to this issue is to integrate laboratory exercises with lecture in a 'studio' format, in which students apply lecture concepts directly to in-class assignments. Another possible solution is to give students 'take-home' laboratory assignments. Both of these methods have shortcomings: the studio format takes away valuable lecture time, and the take-home format provides limited access to the instructor. As such, this work presents a mixed learning method that includes lectures and laboratory work in both the studio and take-home formats, implemented in a junior level signal processing course. Students learn skills during lecture in studio laboratory exercises, and apply these skills to two in-depth take-home projects. Students refine their applied skills during projects, thereby informing a better studio lab experience. In order to assess the student's developed skills, project results are delivered as research papers formatted to comply with IEEE standards, which are submitted for blind review to several faculty members, as well as their peers. Reviewers employ a prescriptive rubric to rate papers as accept/revise/reject and provide associated comments. To assess the success of this mixed learning method, the overall ratings for the research papers from the first project will be compared to the second project, accounting for project complexity. The chief contribution of this work is the presentation of a method for providing laboratory instruction in a mid-year DSP course, demonstrating that this method may be adapted for other courses at similar institutions.

Key words: Mixed learning, Studio labs, Take-home projects

INTRODUCTION

Conceptions of learning engineering are dependent on the learning environment, with students identifying lecture as an atmosphere of testing and calculation while the laboratory setting is associated with applying and understanding (Lin, 2009). Lecture is the most common format of educational delivery, but most engineering students also require knowledge that comes only as a result of hands-on experiential learning (Feisel, 2005; Abdulwahed, 2009). As a result, laboratory experiences are vital in undergraduate engineering curricula, especially in sophomore and junior level engineering courses, as they prepare engineering students for internships, research experiences, and their senior design project.

However, laboratory courses can be difficult to fit into an engineering program at liberal arts-focused university, which requires students to be exposed to appropriate non-engineering breadth, as well as sufficient depth in their engineering education. Auxiliary to this fact, undergraduate-focused universities require faculty members to teach, limiting the availability of instructors for laboratory courses. Owing to this resource limitation, many sophomore and junior level engineering courses in liberal arts-focused universities lack a large number of laboratory experiences. In addition, credit limits and accreditation standards may impose a limit to the number of scheduled laboratory experiences at many universities, making alternatives to the traditional scheduled laboratory period attractive.

Two reasonable solutions to this dilemma are to integrate laboratory exercises with lecture in a 'studio' format, or to give students 'take-home' laboratory experiments or projects. The studio format requires students to apply lecture concepts directly to in-class programming assignments on their personal computers (Whitmal, 2002). Implementing labs in this way allows students to learn engineering skills that practicing engineers are expected to know, with one-on-one access to the instructor. This format has the undesirable side effect of reducing the amount of lecture time available when implemented in a non-lab course. In addition, these types of labs lack time for appropriate reflection, and are designed as simply instructional without any research or development components. On the other hand, the take-home format involves assigning lab projects for students to complete on their own outside of class (Jouaneh, 2009). This category of laboratory experience allows time for proper reflection, and helps students transition from instructional laboratories to a development and research opportunity, such as they would experience in the engineering profession (Feisel, 2005). Although this format does not detract from lecture time, there is limited access to the instructor and detracts from the desired laboratory environment. Furthermore, this method requires extensive out-of-class tutorials, whose completion is difficult to police.

As there are shortcomings associated with both of these methods, this work presents a new method, which combines the positive aspects of each approach. This mixed learning atmosphere includes lectures and laboratory work in both the studio and take-home formats. Students were given in-class laboratory exercises during eight lecture periods, as well as extensive take-home research projects, which were intended to mimic the feeling of independent research by the students. In-class exercises were implemented using simulation software available to students through a cloud-based virtual desktop service. In addition to the in-class labs, students were given two group-based research projects in which they explored research problems requiring the use of these same concepts.

The course chosen to test this method is an introductory junior level course in digital signal processing (DSP). This course was chosen because previous work has shown that hands-on experiences in DSP courses can increase students' desire to learn (Adams, 2004). In addition, DSP laboratories are typically software based, making this course is a good choice for testing this approach because simulation software is available to students everywhere with an Internet connection through the cloud-based virtual desktop service. This work details the mixed learning approach and the assessment methods used to analyze the success of this approach. It is expected that this process will allow students to gain laboratory experience leading to the ability to complete more complex problems.

The focus of this work is to describe a method for implementing laboratory experiences in a mid-year signal processing course, based on the Kolb cycle of experiential learning (Kolb 1984). This method may help signal processing educators implement experiential learning in their courses, and may be extended to other engineering courses.

LITERATURE REVIEW

In their review of the role of the laboratory in postsecondary education, Feisel and Rosa (2005) point out that the importance of laboratory-based learning has changed over time. They report that engineering programs in the early 19th century exposed students to both theory and practice. Then, in the mid-19th century, the focus turned largely to laboratory instruction, and this largely remained standard practice until the mid-20th century, when focus turned to educating engineers more in lecture halls than in laboratories or machine shops. Grayson (1993) explains that in the United States, this evolution of engineering education, can be understood in the context of the changing needs of the society from a newly founded pragmatic country, to one focused on westward expansion, to one focused more on the application of new science to solving problems. Today the importance of the laboratory as well as other hands-on design-centered activities has increased. Seeley (1999) points out that this is in recognition of the fact that many engineering students were completing engineering degrees without sufficient exposure to design and other hands-on experiences. As a result, engineering programs are grappling with how to fit laboratory components into an already crowded curriculum.

As mentioned previously, Lin and Tsai (2009) state that the learning that occurs in a laboratory setting can be considered to be at a higher level than in a lecture: students associate lectures with testing, calculating and practicing, while they feel that the laboratory gives them a chance to develop a deeper understanding of the relevant phenomena they need to learn to be effective engineers. One potential reason for a student's deeper learning is their active engagement with the material in the lab. Another, as Lin and Tsai point out, is subtler: students see laboratory instructors as "supportive tutors" rather than a person who is "simply a lecturer." With this being said, one might expect that students would want their education to focus on laboratories, but Lin and Tsai found that this was not the case – instead students generally prefer a mix of the two.

In work published the same year as Lin and Tsai, Abdulwahed and Nagy (2009), argued that the traditional implementation of labs in engineering education (specifically in chemical engineering, which was their focus) was not effective. So, even if students prefer the mix, as argued by Lin and Tsai, the laboratory portion could be improved. Their comprehensive quantitative analysis was in the context of Kolb's experiential learning cycle model, applied to the traditional laboratory. They define the traditional laboratory as a 3-hour meeting during which students accomplish an instructor-defined set of tasks. In the language of the Kolb theory, the traditional laboratory is mainly ineffective because as implemented they do not require the student to sufficiently explore the prehension dimension of the learning cycle, which is to say: only reading the lab manual before doing the lab, does not set the stage for effective learning during and after lab. Abdulwahed and Nagy found that if the lab manual is supplemented by a "virtual pre-lab" the deficit in prehension is made up. They also suggest that the traditional 3-hour lab does not allow student sufficient time to reflect on the learning process (another dimension of the Kolb theory).

There is a rich tradition of the incorporation of laboratory and hands-on components to DSP courses; see for example (McClellan 1998, Spanias 2005, Cameron 2014, and Mousa 2011). Among the varied topics in the engineering curriculum, DSP is uniquely suited to offer laboratory experiences that are outside of the traditional teaching laboratory. The main reason being that useful lab exercises can be designed so that they are computer-based, and not dependent on lab equipment that is not portable. Furthermore, as Adams and Mossayebi (2004) describe, students can actually complete and extract valuable learning from some lab exercises in DSP without a complete knowledge of the material. They report that a number of DSP-related experiments were developed for a junior-level laboratory course, which students take before the DSP course at their institution. In another example of how laboratory experiences can be incorporated into coursework, Whitmal (2002) describes the use of a "studio" format of laboratory instruction in which class time is used for group-based laboratory experiences. Finally, although more specifically geared to mechanical instrumentation labs, Jouaneh and Palm (2009), describe how students can perform "take-home" labs, outside of class. In their paper, they describe the development of a carefully-designed hardware platform that the students use to complete the labs, something that would not be needed for a DSP-related lab, suggesting that it would be even easier to implement for DSP courses.

MIXED LEARNING PROCESS

As motivated by the literature review, there is a need for further research into the delivery and structure of laboratory material. In addition, as laboratory experiences are so vital for engineering students, it is important to accommodate labs into non-laboratory courses. There are a number of alternatives for the delivery of laboratory experiences that exist in literature and practice. A non-exhaustive list includes:

1. Scheduled laboratory periods
2. Holding out-of-class laboratory experiences, either during lecture or outside of scheduled lecture time (not a scheduled laboratory period)
3. Telecommunicated labs (Ogot, 2003)
4. "Living with the Lab" (Hall, 2008; Moller, 2015)
5. In class studio labs (Whitmal, 2002)
6. Large take-home projects (Jouaneh, 2009)

Each of these solutions comes with a unique set of advantages and disadvantages. As outlined earlier, scheduled laboratory periods may not be possible due to credit limitations, instructor loading, or facility availability. The other alternatives accommodate for this fact by not requiring a scheduled lab period.

Out-of-class laboratory experiences can be difficult to employ if students lack access to equipment or software needed for the laboratory experience. This is not the case for this particular implementation of laboratory exercises for a signal processing course, as the students have access to MATLAB and Simulink through a cloud-based virtual desktop service. While telecommunicated labs are an option, even in a residential university, they are not consistent with the nature the engineering program in question, which places a high value on face-to-face meetings between faculty and students.

Another method of delivering laboratory experiences is "Living with the Lab", as implemented at Louisiana Tech University. In this method, students own their own tools, devices, and programmable controller, so they are able to implement labs at home, on their own time. While this is interesting, having students purchase the software needed for DSP is not needed in this case, as students have access to a cloud based virtual desktop service, which allows them to use MATLAB. However, some of the same principles can be applied to this course, allowing students to work on laboratory experiences at home.

The two remaining solutions are to incorporate laboratory exercises with lecture in a 'studio' format, or to give students 'take-home' laboratory experiments or projects. The studio format requires students to apply lecture concepts directly to in-class software based exercises (Whitmal, 2002). This method allows for students to learn engineering software applications of theoretical information with easy access to the instructor. This does take away from lecture time, and lacks time for student reflection. The take-home format involves assigning projects for students to complete outside of class, either alone or in a group (Jouaneh, 2009). This category of laboratory experience allows time for student reflection, but does not allow easy access to the instructor.

As a result, some combination of the laboratory instruction alternatives was explored. The method used in this work was to combine the studio laboratory approach with the take-home project approach. The reason for choosing these approaches was that they seemed the most suitable for signal processing, for the reasons listed with each alternative described. The solution described is called the mixed-learning approach, and has its roots in the cycle of experiential learning, as previously explained discussed in the literature review (Kolb, 1984).

The foundation of the mixed learning approach is that students are able to develop a deep understanding of skills through an iterative process of learning, applying, and refining. The mixed learning process can be visualized by the flow chart in Figure 1. The cycle formed by this approach is similar to Kolb's learning cycle. Kolb proposed that the optimal learning would be achieved through a cycle of Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation (Kolb, 1984; Abdulwahed, 2009).

Instead of describing this cycle in Kolb's vocabulary, it is presented here translated into terms more commonly used in engineering. The process starts with skills being introduced to students

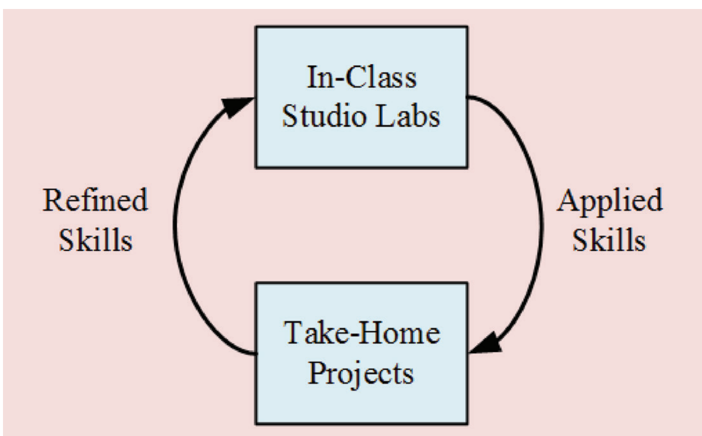


Figure 1. Mixed learning laboratory approach.

through in-class studio labs. The skills that students develop independently in these studio labs are then applied to collaborative take-home projects, where they are further refined, and students are able to reflect on what they have learned. The refined skills can be applied back to studio lab assignments, resulting in students being able to learn more complex skills. Ideally, this process repeats until students approach high proficiency in necessary skills, or alternatively, are able to gain moderate proficiency in more difficult skills. This cycle is informed by Kolb's learning cycle in the following way: in-class studio labs provide concrete experience, and the outcome of the completion of these labs provides an opportunity for reflective observation. By applying learned skills to take home projects, students are asked to perform abstract conceptualization and active experimentation, which can lead to more impactful concrete experiences. In this way, the mixed learning approach is an application of Kolb's cycle to laboratory experiences.

Relating this approach to the course content, the first four studio labs are dedicated to teaching students skills necessary for completion of the first project. The students then apply these skills to the first project, which allows them to research and develop new methods by using these skills. These skills can be built upon to help students perform better in the final four studio labs, which are then applied to a more complex problem in Project 2.

The specific learning outcomes for the signal processing laboratory experience are that

1. Students will be able to use MATLAB and Simulink to perform discrete signal manipulation, filtering, frequency analysis of discrete signals, and image processing.
2. Students will be able to communicate the results of their application of software skills to a technical audience.

The achievement of these learning outcomes is assessed by blind review of student research papers using a rubric designed to measure these outcomes.

The studio labs are designed to cover some of the most essential DSP concepts that show students hands-on applications of signal processing while reinforcing theory learned in the lecture component of the course. The number of labs is constrained to eight, as implementing labs in this way reduces the number of lectures that can be offered to cover theoretical material. This is less than a typical laboratory course, which typically involves 13-14 lab experiments. Because of the limited number of studio labs, take-home lab projects are a necessity. A detailed breakdown of the studio labs material is shown in Table 1. A number of topics were identified as essential based on reported work in other DSP courses (Adams, 2004; Ossman, 2008). The identified essential topics include:

- Discrete signal manipulation
- Filtering
- Frequency analysis of discrete signals
- Image processing

Table 1. Studio Lab Experiments.

Studio Lab	Description
Lab 1	Discrete Signals and Systems
Lab 2	Audio Processing
Lab 3	Fast Fourier Transform
Lab 4	Filter Design
Lab 5	Point/Area Image Processing
Lab 6	Blob Detection
Lab 7	Edge Detection
Lab 8	Equalization & Watermarking

In-class labs are implemented during the scheduled lecture time, following the conclusion of the theoretical background necessary for each topic. This allows for continuity between the absorbed knowledge and applied knowledge, and ensures that students have the theoretical background fresh in their minds while developing hands-on skills. Students bring their laptops to class for the studio style labs. There are a number of benefits to students having laptops in class (Kolar, 2002) and the cloud based virtual desktop service provides students access to laboratory materials anywhere they have a high-speed Internet connection, and allows students with a variety of operating systems and devices to run engineering software. It is also notable that these studio labs could be delivered remotely via the Internet due to the accessibility of software.

The studio laboratory experiments are augmented by two large research projects that require students to further refine skills learned in studio labs. As undergraduate research and collaborative assignments and projects are documented as high-impact educational practices, the project provides significant value to students (Kuh, 2008). The key aspects in designing the take-home projects was that the projects require an application of information from in-class studio labs, and that students be allowed appropriate time for reflection. As a result, the students were provided with research questions, but the execution and exploration of those questions were left open ended. The first project was centered on audio signal processing, as this requires manipulation of discrete signals, applications of filtering, and frequency analysis (McPheron, 2015a). The second project was an application of image processing, for which students had to manipulate of discrete signals, apply filters, and extend these skills to image processing.

The first project required students to apply signal manipulation skills learned in the first four studio labs to the development of a novel reverberation algorithm for audio signals. A simple reverberation algorithm is shown in Figure 2 (McPheron, 2015b). Students chose to explore a number of topics related to reverberation including the use of chorus modulation, vibrato, and wavelet compression techniques. The technical steps associated with this project are:

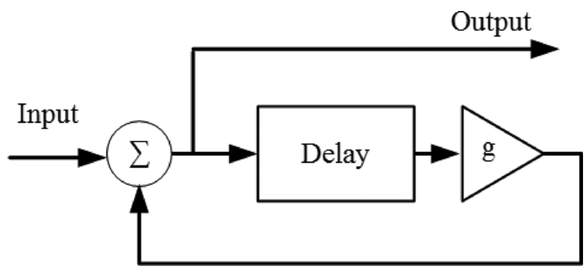


Figure 2. Simple Reverberation.

1. Research algorithms
2. Develop a novel algorithm or area to study
3. Implement reverb algorithm in MATLAB and Simulink
4. Test algorithms
5. Iterate until desired result

The second project required students to apply image processing skills developed in the last four studio labs to tracking multiple objects through video (McPheron, 2014). A still frame from the video used is shown in Figure 3 (McPheron, 2015b). Students were asked to further develop a

Figure 3. Still frame for multiple-identical blob tracking.

tracking algorithm designed to follow multiple blobs through the video. This project is significantly more complex than the first project, requiring 8 technical steps, opposed to the 5 steps needed for Project 1. These steps are:

1. Research algorithms
2. Develop a novel algorithm or area to study
3. Get frames from video
4. Extract blobs
5. Suppress extra blobs
6. Implement tracking algorithm in MATLAB and Simulink
7. Test algorithms
8. Iterate until desired result

For these projects, students were split into small multidisciplinary teams of 2 or 3 students for work on the projects presented in this paper. The overall student population was composed of 11 students from disciplines including Electrical Engineering, Computer Engineering, and Computer Science.

Each project begins with a proposal phase, in which students propose a topic for study in the form of an abstract. The instructor is responsible for guiding the students in their research by approving or revising the abstract and providing constructive feedback meetings with each group. The main deliverable for each project is a technical report, written in IEEE standard format, which details the theory and methods used in the project. In addition to the required technical report, students are responsible for submitting any code written for the project, in order to verify the skills that the students have applied and confirm that students have prepared their own assignments.

ASSESSMENT

To assess the effectiveness of this method, a direct assessment tool is used. Although student surveys can be used as an indirect measure of the method, the student's perceived understanding is often different than actual performance (Bernadin, 2007).

As a direct method of assessment, student-project technical papers are submitted to several faculty members for blind review. These faculty members rate student ability using a prescriptive rubric, shown in Table 2. The rubric was designed with two purposes in mind. The first, and most important, is that the rubric assesses the achievement of the learning outcomes for the laboratory experience. This means that student completion of technical tasks and ability to communicate their results should be measured. The second purpose is to expose students to a review process similar to a conference. Many conferences possess unique rubrics for reviewer decision, which aided in

Table 2. Prescriptive rubric for assessment.

	Excellent (2)	Adequate (1)	Weak (0)
Format	Paper follows the IEEE format and is easy to read	Minor formatting or structure issues	Major formatting or structure issues
Writing	The writing is clear and mostly free from grammatical mistakes	Minor grammar mistakes, unclear presentation	Major grammar mistakes, unclear presentation
Knowledge	Clear knowledge of theory	Some knowledge of theory	Poor knowledge of theory
Application	Results displaying high proficiency in applied skills	Results displaying some proficiency in applied skills	Results displaying poor proficiency in applied skills
Justification	Clear justification of methods used	Some justification of methods used	Poor justification of methods used
Originality	Novel concept or application	Somewhat novel concept or application	Unoriginal concept or application

the design of this rubric. Three categories (knowledge, application, and originality) are aimed at measuring student technical ability, and three categories (format, writing, and justification) reflect student ability for technical communication.

The student-written papers represent the student(s) cumulative understanding of the subject obtained through multiple class and lab sessions. The papers are evaluated using six categories. Three categories (format, writing, and justification) reflect student ability for technical communication and three categories (knowledge, application, and originality) are aimed at measuring student overall understanding, technical skill and the ability to apply additional/available techniques or options in a tool (such as MATLAB) that were not directly shown in class or lab and, the ability to logically reason out their choice; respectively.

The goal of the hybrid-mixed learning approach is to provide an interactive instructor led component and a self-paced self-learning component as part of the same course. To this end assessment or evaluation of student work also had to be done in a hybridized fashion i.e. in-class workbook to assess in-class work and a lab report assessment that captures the self-learning component. Typically the rigor of in-class examples tend to be lower compared to the self-learning component simply because of the class time limitation.

Therefore the desired outcomes of the interactive in-class component are:

1. Familiarizing the students to the concept/tools currently being introduced
2. Completion of an entire self-contained lab exercise for the purposes of understand the process of experimentation

The desired outcomes of the self-paced self-learning component are:

1. Deepening the understanding of the concept/tool currently being considered through detailed guided instructions along with interwoven questions that test students' understanding.

2. Enabling the students to independently perform the process of experimentation by being able to setup and run the lab exercise (similar to the one from class) on their own. This task can be accomplished by providing detailed instructions of the where and how to find the answers rather than giving the answers directly. For instance, in MATLAB, if a student needs to perform a matrix multiplication, given the student a link to the help page on how to perform matrix multiplication rather than giving them an m-file or a macro.
3. Enabling the students to acquire technical writing and communication skills, while working with peers; this is achieved by writing detailed lab reports.
4. Introducing the students to the process of expert (in a particular field) review and evaluation; achieved through writing of the IEEE styled paper for faculty review.

To measure the overall efficacy of the hybrid approach, the scientifically acceptable technique would be to compare the understanding metric (obtained through tests or surveys) of two student groups: one control group with non-hybrid labs and one with the hybrid approach. However, this would be prevent the students in the control group in gaining the benefits of the hybrid approach. Therefore a safer alternate is to compare the understanding metric of students from previous years. This can be done by comparing responses to multiple specific exam questions that deal with the multiple specific corresponding concepts from lab. Furthermore the assessment of the student written papers provide an additional opportunity to evaluate student understanding.

Format, writing, and justification are relatively easy to assess. The standard paper format is provided to the students in the form of a template. Checking for mere consistency with the provided template, grammatical and spelling errors and, sentence formation to argue the cause-effect or logical deduction; respectively would suffice. However assessing knowledge, application and originality are not trivial especially due to the blind review process utilized.

To accurately assess student knowledge of theory, the blind reviewer needs to be a subject expert. The instructor assigning the papers can easily identify and assign the right papers to the right reviewers. As theoretical concepts assessed are universal, the reviewer would only need the instructor to provide the intended set of conceptual understanding to be displayed in the paper to assess knowledge of theory. Application of skills (such a MATLAB code or Excel plotting or curve fitting) can all be easily assessed by the reviewer by looking at the data and results provided. Again the list of tools expected to be used is provided to the reviewer by the instructor.

The most difficult portion of assessment is determining originality and or justification. The papers are the work of undergraduate third/junior year engineering students. Therefore the focus is not on research originality but on the originality in application of known (through class) and self-learned techniques to the way in which data is *produced, processed, and presented*. For instance, the recommended method for plotting is through built-in MATLAB functions. However a student may choose to export raw data, import in Excel and process the data there with additional ways of presenting the results. This shows originality of application of techniques. When taken along with the logical reasoning provided as justification of the choice for data processing, the reviewer is able to ascertain the originality of application. A similar approach was shown to estimate non-directly-measurable engineering design skills in (Schilling 2012).

A total overall score between 9 and 12 yields a decision of accept, scores between 6 and 9 returns a decision of revise, and scores less than 6 result in a decision of reject. Given these guidelines, participating faculty members returned comments and a decision for students. The comments associated with the review are invaluable in providing students a feedback measure of their skills. In addition to the expert reviews, papers are also submitted to the other groups for peer review. The combination of peer and expert reviews are used to assess student performance.

To determine if this method was successful, rubric scores from the first project may be compared with scores from the second project. The raw scores of this may by misleading, as the problem complexity is not the same for the two projects, so complexity must be accounted for. When complexity is taken into account, students showed improvement in performance the second project for two likely reasons: feedback from the first project and further refined skills developed by using the mixed-learning method.

COMPLEXITY RATIO DETERMINATION

A standard technique used to estimate the time needed for a test is having the instructor or a teaching assistant take the test, then applying a multiple to estimate the time needed for a student. To estimate perceived time requirement, difficulty or emotional intensity researchers use the technique of surveying relevant subjects. The data (usually categorical) thus obtained is analyzed using weighted ranking (Carrol and Lovejoy 2005) or categorical frequency count (Kelley and Wicklein 2009) technique.

Using time required as a close substitute for project complexity. A weighted averaging approach can be used to ascertain the relative complexity of two projects along with other relevant aspects of the projects involved. Table 3 shows the perception survey criteria used to determine the complexity ratio of Project 2 with respect to Project 1. The average complexity ratios from multiple experts represent the final value of this metric. In general a higher complexity ratio implies higher learning. For example, if learning to test MATLAB programs is a stated outcome; then a project where the test case is provided would not lend itself well when it comes to achieving this learning outcome. On the contrary if the students are expected to develop their own test cases, it increases

Table 3. Project complexity weighting.

	0 - no; 1 - yes; Scale of 0 - 1, 0 is minimal and 1 is maximum	Weights (0-1)	Project 1 (baseline)	Project 2
1	Is the project a software only project?	w1	x1	y1
2	More than one software/OS required?	w2	x2	y2
3	Software to software or OS interaction manual?	w3	x3	y3
4	Amount of coding needed. (0-1)	w4	x4	y4
5	Are the input test file/case/parameters provided?	w5	x5	y5
6	Need to generate a test file/case/parameters?	w6	x6	y6
7	Time needed to generate and run the test. (0-1)	w7	x7	y7
8	Calculus or advanced algebra needed?	w8	x8	y8
9	Expert's time to complete the same task. (0-1)	w9	x9	y9
10	Expert's self-declared knowledge on the subject. (0-1)	w10	x10	y10
11	Expert's estimate of time needed for average student (multiple of expert's time)	w11	x11	y11
12	Expert's estimate of optimal student group size. (1-4)	w12	x12	y12
13	Expert's estimate of difficulty relative to lab 1. (multiple of lab 1 difficulty)	w13	x13	y13
		Weighted Score	X	Y
		Complexity ratio		Y/X

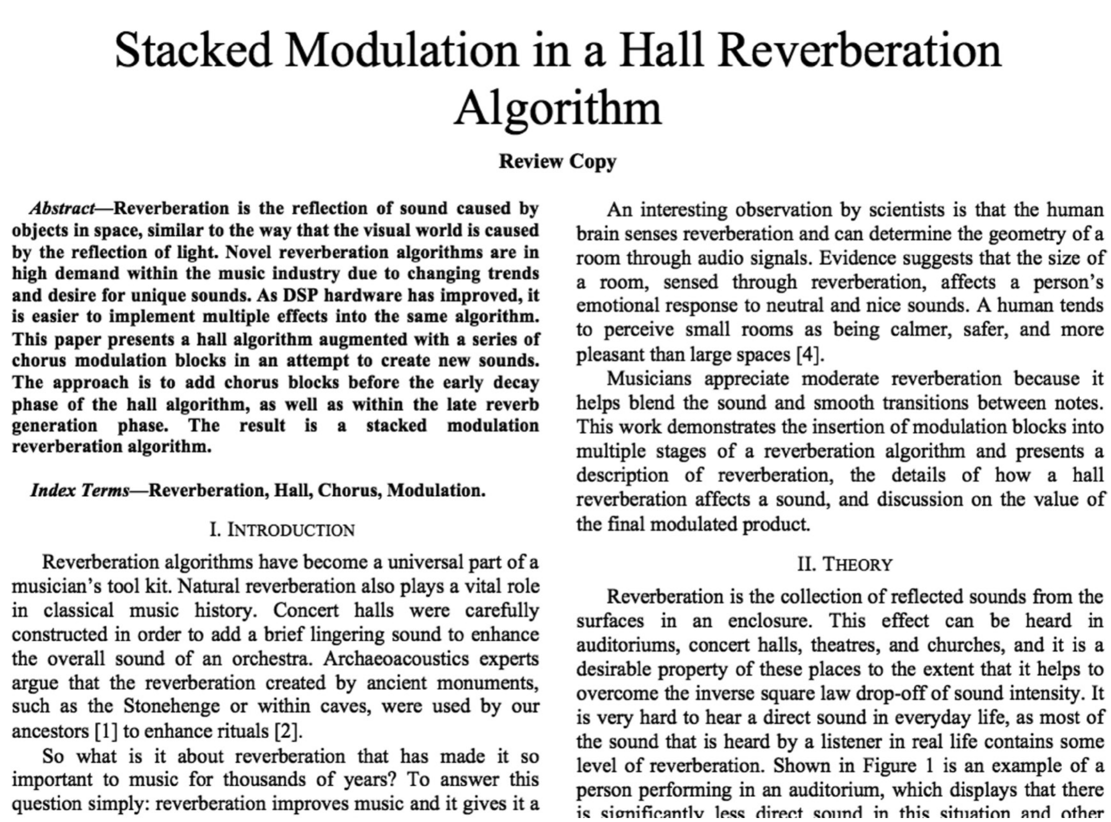
learning, skills and consequently the complexity ratio would be higher compared to when the test case is provided.

RESULTS

Examples of Student Work

This section shows several excerpts of typical student submissions for the two take-home projects. Students were able to complete short four- to six-page research papers for both projects. These projects allowed students time for reflection and refinement of skills, and allow students to extend from instructional laboratories to research and developmental laboratories, which prepares them for research experiences, internships, senior design projects, and a future career as a practicing engineer.

In order to complete these projects, the students were provided the IEEE Microsoft Word format and were required to include an abstract, introduction, theory, methods, results and a discussion/conclusion. Figures 4 and 5 show two excerpts from the first project, related to audio signal processing, while Figure 6 and 7 shows an expert from the second project, related to computer vision. These examples display the quality of work that students were able to produce.



Stacked Modulation in a Hall Reverberation Algorithm

Review Copy

***Abstract*—Reverberation is the reflection of sound caused by objects in space, similar to the way that the visual world is caused by the reflection of light. Novel reverberation algorithms are in high demand within the music industry due to changing trends and desire for unique sounds. As DSP hardware has improved, it is easier to implement multiple effects into the same algorithm. This paper presents a hall algorithm augmented with a series of chorus modulation blocks in an attempt to create new sounds. The approach is to add chorus blocks before the early decay phase of the hall algorithm, as well as within the late reverb generation phase. The result is a stacked modulation reverberation algorithm.**

***Index Terms*—Reverberation, Hall, Chorus, Modulation.**

I. INTRODUCTION

Reverberation algorithms have become a universal part of a musician's tool kit. Natural reverberation also plays a vital role in classical music history. Concert halls were carefully constructed in order to add a brief lingering sound to enhance the overall sound of an orchestra. Archaeoacoustics experts argue that the reverberation created by ancient monuments, such as the Stonehenge or within caves, were used by our ancestors [1] to enhance rituals [2].

So what is it about reverberation that has made it so important to music for thousands of years? To answer this question simply: reverberation improves music and it gives it a

An interesting observation by scientists is that the human brain senses reverberation and can determine the geometry of a room through audio signals. Evidence suggests that the size of a room, sensed through reverberation, affects a person's emotional response to neutral and nice sounds. A human tends to perceive small rooms as being calmer, safer, and more pleasant than large spaces [4].

Musicians appreciate moderate reverberation because it helps blend the sound and smooth transitions between notes. This work demonstrates the insertion of modulation blocks into multiple stages of a reverberation algorithm and presents a description of reverberation, the details of how a hall reverberation affects a sound, and discussion on the value of the final modulated product.

II. THEORY

Reverberation is the collection of reflected sounds from the surfaces in an enclosure. This effect can be heard in auditoriums, concert halls, theatres, and churches, and it is a desirable property of these places to the extent that it helps to overcome the inverse square law drop-off of sound intensity. It is very hard to hear a direct sound in everyday life, as most of the sound that is heard by a listener in real life contains some level of reverberation. Shown in Figure 1 is an example of a person performing in an auditorium, which displays that there is significantly less direct sound in this situation and other

Figure 4. Excerpt of student work studying stacked modulation

The student work displayed in Figure 4 is the paper from the first project that was rated highest by both the expert and peer reviews. This paper received the highest score because the authors were able to clearly communicate the technical content with sufficient detail to allow both sets of reviewers to understand the material. On the other hand, the submission displayed in Figure 5 was rated as the median score of those submitted for Project 1. This paper was rated lower because, although the results were very good, the students did not provide adequate description of the theory and methods, and their presentation of the material left some ambiguity.

The student submission displayed in Figure 6 is the paper from the second project that was rated highest by both the expert and peer reviews. This paper received the highest score because the authors were able to portray a good grasp on the technical content and showed mathematical rigor in their theory section. Both the peer and expert reviewers rated the student work in Figure 7 as second highest. The score for this paper was the result of formatting errors, and unexceptional communication of the theory.

A Closer Look into Instrumental Modulation

The Exploration of Electronically Applied Vibrato and Reverberation

Review Copy

In musical performance, various techniques are employed to increase audience interest in the music. One common technique is to apply vibrato to a sustained note. Physically, vibrato is slight oscillations of lower frequencies based on a sample frequency. An accurate representation of this effect is difficult to reproduce artificially due to the complex physics behind the vibration. However, the novel approach of applying a known low frequency vibrato algorithm with a reverberation algorithm to a 'dry' or clean source produces promising results. This method was tested by running clean audio recordings of a flute, violin, and trumpet through the combined algorithm to produce artificial vibrato. The result was compared to an audio recording of the instruments' natural vibrato.

I. Introduction

Since the Baroque era (c. 1600-1750), vibrato has been widely used by opera singers and orchestra members as a way to expand the music and insinuate a high level of professional skill. [1]. The ideal vibrato should slightly distort the original pitch, add color, and add texture. [2].

Today, vibrato is used as a tool of the modern violinist, flutist, and trumpeter. These instruments have been converted to electronic files that are used in popular music styles. [3] created such as room size (volume), type of material the room is composed of, and what objects the sound waves bounce off of, or diffusion. The major factor in reverberation is the time it takes for the sound to bounce off a medium and enter ones ear or microphone; this is called the reverberation time, which can be expressed by the following equation.

$$RT_{60} = k \cdot \frac{V}{A} \tag{1}$$

The RT_{60} is the time it takes for the sound level to drop by 60 dB. The k is a constant of 0.049 feet or 0.161 meter. The V and A variables are defined as the room volume and equivalent absorption surface, respectively.

While there are natural sources of reverb, artificially created types also exist. Software synthesis using synthesizers, effects processors, audio cards, and digital audio applications can simulate a reverberated environment. Using digital system processing techniques and algorithms, one can mimic a natural reverb effect.

The algorithm that is used for testing is called the plate reverb structure. It is composed of two filter/delay banks and a feedforward factor.

Figure 5. Excerpt of student work studying vibrato modulation

I. Introduction

Research in the field of tracking objects through video has become common; however, tracking multiple objects has yet to reach that summit [1]. The reason for this is that it can be seen as challenging because sometimes the objects being tracked can appear to be similar in color and/or shape. Objects that are being tracked are commonly defined as blobs. Blob detection is a mathematical method that detects areas of digital images that differ. It achieves this by searching for definitive properties such as color or the amount of pixels.

The method utilized in this work identifies and tracks blob movement through various sequential pictures or frames. Specifically, the code tracks two moving white colored ping-pong balls in a black colored box. It achieves this by detecting differences within colors of the pixels. To improve accuracy the color pictures were converted to grayscale. A multi-scale Laplacian of Gaussian filter was used determine the change in pixels. This allows for the detection of different sized, similarly colored blobs.

The focus of this work is on how different scoring algorithms effects the accuracy of the Hungarian algorithm. In the past, work has done by McPheron to track multiple blobs in distances and times within Minkowski Space [4]. This is important for multiple blob tracking because it provides a link between an objects position in space with its position in time.

$$d = \left(\sum_{i=1}^{n} |x_i - y_i|^p \right)^{\frac{1}{p}} \tag{1}$$

The current system uses a variation on the Minkowski metric called the Euclidean metric. Euclidean metric is simpler than the Minkowski because it does not consider time to be linked with space. Thus, the Euclidean metric has the difficultly of being applied to multiple objects across many frames.

$$d = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2} \tag{2}$$

Another type of distance metric is the City Block or Manhattan norm. This metric can be less accurate then the Euclidean because it treats distances between two objects as stepped squares, not a triangle.

$$d = \sum_{i=1}^{n} |x_i - y_i| \tag{3}$$

Figure 6. Excerpt of student work studying object tracking

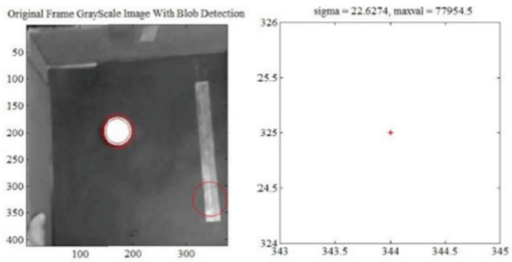


Fig 10. Frame 200: (Left) Grayscale image with blob detections. Notice the pong ball is still detected multiple times but the tape is detected less. Threshold = 0.99. This is progress compared to Figure 3 but still needs correction. (Right) X,Y coordinates of pixels of where the center of the blob with the greatest contrast is located. Even though the left image shows that the pong ball is also included, the coordinates point to the blob defined over the white tape, not the ping pong ball.

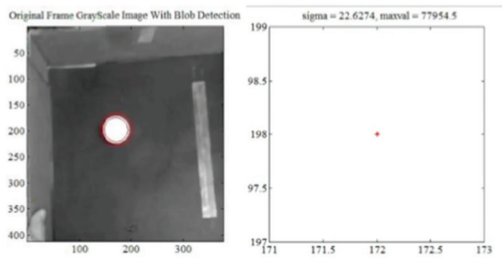


Fig 11. Frame 200: (Left) Grayscale image with blob detections. Notice the pong ball is still detected multiple times but the tape is no longer detected. Threshold = 0.9999. This fixes the issue from Figure 4. (Right) X,Y coordinates of pixels of where the center of the blob with the greatest contrast is located. The coordinates point to the ping pong ball.

It can be assumed the addition of the blurred edge detection does not negatively impact any of the other detected frames. To check this, the same filter was applied to frame 2, the frame that worked with the non-modified code (see Fig 15).

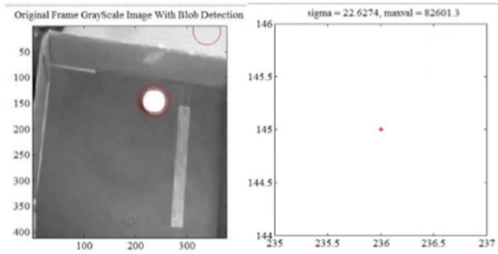


Fig 12. Frame 100: (Left) Grayscale image with blob detections. Notice the pong ball and the box sides are detected. Threshold = 0.9999. (Right) X,Y coordinates of pixels of where the center of the blob with the greatest contrast is located. The coordinates point to the ping pong ball but box blob exists.

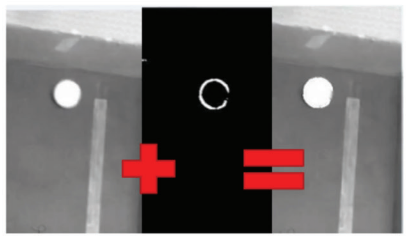


Fig 13. Frame 100. (Left) Grayscale still movie image. (Middle) Blur and edge detection filter. (Right) Original and edge detected image combined to create a more defined blob. Notice the crisp white lines around the circumference.

Figure 7. Excerpt of student work studying object tracking

RESULTS OF BLIND REVIEW

The raw scores from expert and peer review are shown in Table 4 and Table 5. The scores for Project 1 are found in Table 4, while the scores for Project 2 are found in Table 5. One useful observation is that expert and peer reviews tend to agree on rank order of papers. It is also notable that peer review scores are uniformly higher than expert review scores.

As outlined earlier, the presupposition of this paper is the improvement in the overall class performance i.e. project paper evaluation scores as a consequence of the mixed learning approach expounded herein. A quick comparison of the raw scores tabulated in Tables 3 and 4 seems to be in direct contradiction to the expressed outcome at the beginning of this paper. However this contradiction can be readily explained as follows.

Table 4. Raw scores for Project 1.

Group	Expert Review Average	Peer Review Average	Average of Peer and Expert
1	10.5	11.2	10.85
2	8.75	10.7	9.725
3	8.75	9.8	9.275
4	8	9.8	8.4
5	7.25	8.6	7.925

The raw scores shown in Tables 3 and 4 do not account for the project complexity differential between the two project assigned. Project 2 was more complex than Project 1. This statement in itself provides no value in terms of how the scores are to be compared. In order to quantify the complexity differential, a complexity ratio was developed through a complexity perception survey of the experts, as discussed earlier. The complexity of each project was rated on a scale of 1-10 and the complexity score ratio was calculated to be 5/8. This is interpreted to mean that the complexity of Project 2 was at least 1.6 times that of Project 1. The complexity ratio factor was applied to the expert review scores only, as the reviewers were unaware of the change in project complexity and thus tended to view Project 2 report less favorably than Project 1.

When the complexity-normalized scores are compared, it is clear that the overall scores for Project 2 improved with respect to Project 1; as shown in Figure 8. The scores for all five student groups for the Project 1 (AVG1, solid line) are generally higher than the raw scores for Project 2 (AVG2, dotted line). Group 3 scored higher even when scores were not normalized, this group showed the largest improvement in performance between the two projects. When comparing the complexity-normalized scores for Project 2 (AVG2_COMP, dashed line) with the scores for Project 1, all the student groups scored more except group 5. Group 5's complexity-normalized Project 2 score was within 2% of Project 1 score.

Table 5. Raw scores for Project 2.

Group	Expert Review Average	Peer Review Average	Average of Peer and Expert
1	8.5	10.9	9.7
2	8	10.8	9.4
3	4.5	9.8	7.15
4	6	9.5	7.75
5	6	8.4	7.2

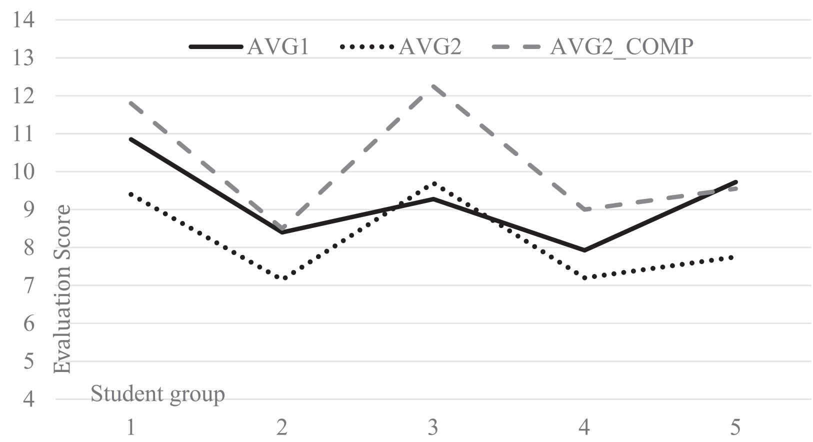


Figure 8. Un-normalized scores of Project 1 & 2 and, complexity-normalized score for Project 2 .

Thus, when the increase in project complexity is accounted for, the overall class project performance improved by 10.7 %. The performance of all groups but one increased, with the one group scoring –1.83% relative to Project 1. Figure 9 shows the change in the average total class project scores for Projects 1 and 2 and complexity-normalized Project 2 score.

To further analyze the result, the project scores were broken down into two categories, namely, technical and writing scores. It is widely recognized that general writing skills and, in particular, technical writing skills are areas of concern and constant development for engineering educators. Looking at the scores separately leads to some interesting observations.

Figure 10 shows the breakdown of the total scores for all five groups along technical and writing categories. Figure 10 also shows Project 1 and complexity-normalized Project 2 scores. Group 3 had

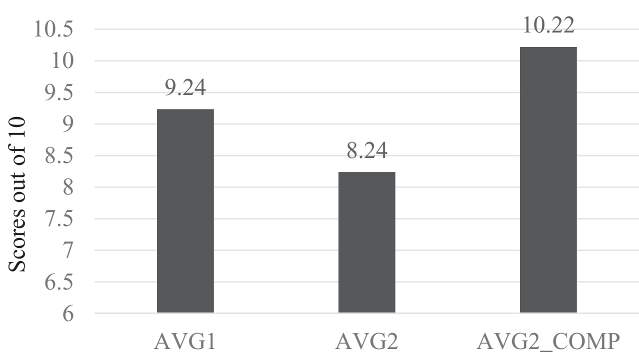


Figure 9. Average total class project scores.

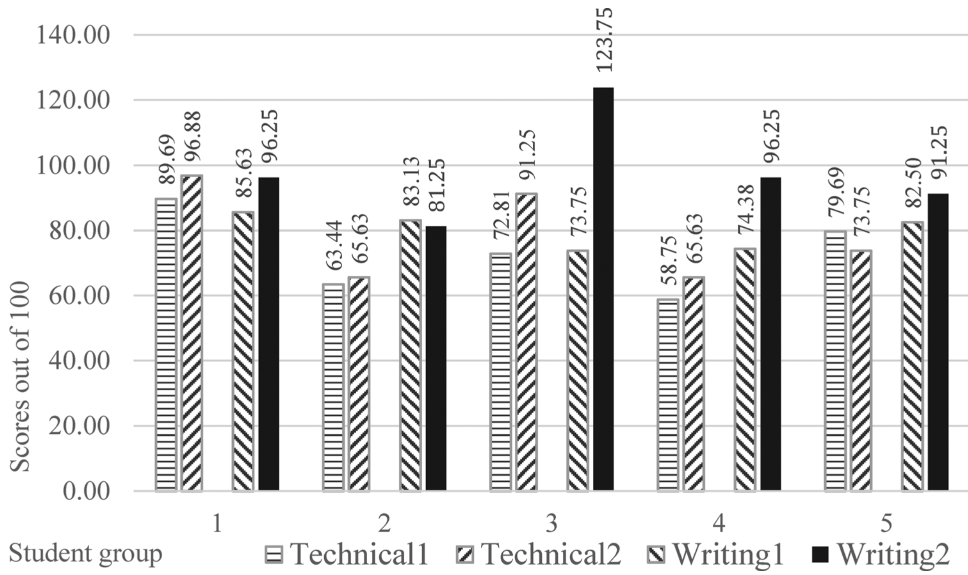


Figure 10. Technical and writing score breakdown.

the largest improvement in writing and in technical aptitude. All groups except group 2 improved their writing scores. Group 2 showed a decrease in writing score of –1.875% with a small increase in technical aptitude score. Group 5 displayed the exact opposite of Group 2, i.e. a decrease in technical aptitude with an increase in writing score.

Table 6 summarizes the changes in the technical and writing scores for all five student groups. The average increase in the technical aptitude was 5.75% with a change range of –5.93% to 18.43%. The average increase in writing score was 17.875% with a change range of –1.875% to 50%. The score breakdown uncovers an interesting consequence of the mixed learning approach, that is, irrespective of the complexity of the project, writing skills improve 3 times more of technical aptitude improvement.

Table 6. Summary of changes in technical and writing scores

	Technical Score Delta	Writing Score Delta
Group 1	7.19	10.63
Group 2	2.19	–1.88
Group 3	18.44	50.00
Group 4	6.88	21.88
Group 5	–5.94	8.75
AVG	5.75	17.88

Note that complexity normalization is not needed for the peer reviews, as students seem to be fully aware of the difficulty of the problem when assigning scores. This is unsurprising, as students commiserate with each other in the completion of challenging tasks. It may also be that students give each other the 'benefit of the doubt' when reviewing.

CONCLUSIONS

This work describes and verifies a mixed learning approach for accommodating laboratory experiences in a non-lab course. This is particularly important in middle years of engineering education, as students require hands-on practice before embarking on a capstone senior design journey, and their courses may be deficient in laboratory experiences. Although this work was specific to a junior level DSP course, it is likely that this method can be applied in other engineering courses.

The results suggest that the application of the mixed learning method allows students to improve their skills and to tackle more complex problems. The cycle of Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation, represented in simpler terms as the mixed learning method allowed students to build upon skills and information through experiential learning. In fact, when controlling for problem complexity, students performed better on the second project than the first project. This result is promising for the extension of this method to other engineering courses, and especially to courses with no formal lab sections. The benefits of providing laboratory experiences outweigh the time taken away from lecture to implement these labs.

In addition to the quantitative results, the instructor reports qualitatively that students performed better on the studio labs in the second half of the course. Informal student response to this method was generally positive. Students appreciated having high expectations placed on them and the opportunity to research and develop new techniques. In addition, developing these laboratory experiences proved interesting and invigorating, as it helps to keep the instruction relevant and practical.

There are a number of benefits to mixed learning laboratories for sophomore and junior level students. This method can provide an integration of lab experiences into non-lab courses and can provide hands-on experience that would be otherwise missing. In addition, providing these experiences during the middle years of the curriculum allows for students to discover research opportunities and grow in their ability to contribute scholarly work (Kuh, 2008; Zydney, 2002).

Although this approach was fairly successful in its first implementation, there are still a number of areas for further exploration and optimization. Related to project design, an expanded library of possible projects should be constructed so that students do not rehash other's work. When considering the execution of this method, it is very important to find appropriate scheduling for the studio labs as timely delivery for their use in the project. It may also be useful to structure more project checkpoints to keep students on task and focused on completing the project.

Future work on this method could follow a number of avenues. It would be useful to characterize the types of mistakes that students commonly make, for example, when a citation is needed, or the appropriate order of ideas (putting the cart before the horse). These results could be helpful to inform educators of areas to highlight in order improve the effectiveness of this method. It may also be useful to test the impact of random team assignments versus self-selected teams for the completion of the projects. Finally, it would be of value to extend this approach to other engineering courses.

In conclusion, the presupposition that a mixed learning approach applied to a non-laboratory junior year digital signal procession class will improve student's grasp of the subject matter is supported by the project evaluation score analysis presented. Furthermore, it was shown that as a consequence of having two projects within the span of a single semester, the student's writing skills improved by a factor of three relative to their technical aptitude improvement.

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