2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #38474

Work In Progress: ”Flash-Labs” as a Tool for Promoting Engagement and Learning in Signals and Systems for Biomedical Engineering Course

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Introduction

Signals and systems is an important course for engineering students to master because it lays the foundation for digital signal processing (DSP), which is at the core of most technologies in use today. Signals and systems is usually taught from the perspective of mathematical modeling of systems, where the signals analyzed are mostly periodic and predictable. This might limit the vital connections that students could make between theory and application to the real world [1-2]. The focus of signals and systems for Biomedical Engineering (BME) is on modeling and analysis of physiological signals, which are typically not periodic and are not always predictable. This presents a unique educational opportunity in that BME students get to work with their own physiological signals. In this way, they can relate the concepts and models to how their own bodies operate as they analyze their blood pressure, heart rhythms (ECG), pulse oximetry (PPG), muscle stimulation (EMG), brain activation (EEG), and other relevant signals.

Motivation

Signals and Systems for BME is a required course for seniors at Wentworth Institute of Technology, offered once per year in the spring semester. About 20 students are enrolled in each section of the course, with two to three sections offered, depending on enrollment, all taught by the same instructor. As a 3-credit lecture only course, with three fifty-minute lectures per week, there is not enough time for full-length labs. It is well documented that labs and hands-on activities help students develop in-depth knowledge of concepts and gain practical skills [3-5]. The instructor has taught the course to eleven cohorts of students over the past five years and, from early on, noticed that the traditional mathematical focus and delivery of the lectures was difficult for students to grasp and not engaging them enough. Furthermore, student responses to end of semester course evaluations indicated that labs and hands-on activities were needed. It made sense to find ways to teach the fundamental concepts and methods of BME signals and systems in a meaningful and engaging way.

Flash-lab Implementation

To address the need for hands-on activities, "Flash-labs" were first introduced into the course in the spring of 2019 semester. Flash-labs are hands-on activities which students perform in class as part of the lecture, at least once per week. The focus of each flash-lab is to illustrate a concept taught in lecture through a targeted simulation or hands-on activity in which students may capture and analyze one of their own physiological signals. Flash-labs are designed to take between 20-30 minutes in class, with about 60 minutes of follow up work to be completed outside of class. Students execute the activities, then report on and discuss their findings with their classmates in small groups and through reports and reflective posts in their DSP-Portfolio.

DSP-Portfolio

Originally, after completing each Flash-lab, students submitted their findings and observations as assignments onto the learning management system (LMS). However, this was limiting because only the instructor got to review the assignments. To further enhance in-class collaboration and engagement, in the spring of 2022, DSP-portfolios were added for students to share their results, findings, and key learnings through posts and reflections. The goal of the DSP-Portfolio is for students to document their findings and to share and learn from others. At the beginning of the semester, each student creates their DSP-Portfolio on a Google site from a template provided by the instructor. The portfolio includes explanations of key concepts, and reports of their findings.

Flash-lab Examples

A list of some of the flash-labs conducted in the course is shown below. Appendix A includes more detailed descriptions of selected Flash-labs.

- *Signal detectives*: students learn how to analyze and represent signals and waveforms graphically and analytically. Students learn to "take" the "vital signs" of signals, such as amplitude, period, frequency, and phase-shifts and turn them into mathematical expressions.
- *DSP in hearing-aids*: students learn about DSP architectures and adaptive filtering.
- *ECG modeling*: using pen and paper and Matlab, students apply time and frequency domain methods to analyze heart rhythms and detect abnormal patterns.
- *Heart rate variability (HRV)*: over a two-week period, students collect their own HRV data with mobile devices and analyze data to track their own alertness and stress levels.
- *Point-of-care ECG*: students monitor and analyze their own heart rhythm with wearables.
- *EMG*: as a workshop, in cooperation with engineers from Delsys, students record their own muscle activation signals and analyze signal characteristics in time and frequency domains.
- *Insulin regulation mechanism*: Matlab/Simulink activity in which students explore feedback control of physiological systems and sensitivity to adjustment of parameters.

Thematic Analysis Methodology

The effectiveness of Flash-labs will be evaluated using a thematic analysis approach, following established methods, with themes identified solely based on collected data without pre-existing code sets [6-7]. Thematic analysis provides a way to systematically analyze qualitative data. Thematic analysis is performed as a five-step process: data acclimation and familiarity; line-by-line coding; initial theme identification; further theme expression; review of themes based on the complete data set. At this stage in the analysis, themes are named and aggregated for a preliminary analysis and comparison by both authors. We intend to base our preliminary analysis on student self-perceptions of the value and learning derived from Flash-labs.

Data Collection

The data elements to be collected include the following:

DSP-Portfolios, diagrams, discussion postings: the accuracy, quality, detail, and clarity in describing the underlying concepts and results can be evaluated from these sources.

Classroom observations: help assess engagement, participation, and collaboration.

Surveys: with questions rooted in a metacognitive approach designed to evaluate how students internalize concepts as well as their transference to other courses [6]. Sample survey questions include the following:

1. *How has the Flash-lab impacted your understanding of the course material?*
2. *What concepts from other courses have you applied in this Flash-lab?*
3. *Have DSP-Portfolios helped you think about and share what you learned in the course?*

Preliminary Results and Discussion

From in-class observations conducted in the spring semester of 2022, it appears that inclusion of Flash-labs into the course has been effective in meeting the goals–students are engaged, actively participate, and collaborate with peers while conducting Flash-labs. Student reports indicate that they are able to make connections to concepts learned in other courses. Some students also report that they are able to apply DSP concepts learned in the course to their senior capstone projects, which they are conducting concurrently. While not definitive, these preliminary observations indicate that Flash-labs seem to be effective. Further data analysis would confirm this.

Conclusions and Future Work

The next stage of this research involves analysis of the thematic coding elements compiled from data sets collected from end-of-semester course evaluations. While Flash-labs may not be a complete replacement for a full laboratory class component, it does appear that they help students relate to and internalize core fundamental concepts within the compressed time frame and are eager to collaborate with each other. Another extension of the analysis may involve conducting photovoice analysis, focusing on themes extracted from the student DSP-Portfolios [9]. One example of such a photovoice queue involves students presenting and reflecting on diagrams and findings they document in their DSP-Portfolios [10]. Overall, the analysis framework presented in this paper seems well suited for the goals of the research: to evaluate how Flash-labs promote engagement and learning of Signals and Systems for BME.

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Appendix A: Detailed Examples of Flash-labs

Flash-lab Example 1: ***Signal detectives*:** The formulas and graphs utilized in signals and systems can look intimidating. The goal of this initial flash-lab is to train students as “signal detectives” to tackle problems which may look difficult. For example, when modeling signal waveforms, students learn to take the signal’s “vital signs” such as units, scale, amplitude, periodicity, etc., making the analysis more approachable, even when faced with “scary” looking graphs or equations. This gives the student a few anchor points from which they can continue with analysis of the signal waveforms.

Flash-lab Example 2: ***Nyquist sampling rate***: One of the key takeaways from the course is understanding how to sample signals to obtain an accurate representation in digital form. For example, when introducing Nyquist theorem for signal sampling, students watch videos showing why the wheels on cars on TV look like they are spinning backwards (which appear to counter the physics of motion!). In this pen and paper activity, students trace a waveform sampled at different rates.They identify what is an effective sampling rate and when sampling breaks down resulting in aliasing. Students reflect and share their observations through their DSP-Portfolios.

Flash-lab Example 3: ***HRV analysis to detect stress***. Heart Rate Variability (HRV) correlates with stress and alertness. Most popular wearable devices in use today, including Apple watch and Fitbits compute HRV with digital signal processing of heart rate data collected by sensors on the device. In this activity, students collect their HRV data over a two-week period, using freely available tools to measure HRV with a cellphone (https://welltory.com/). In class, students analyze, interpret, and reflect on the patterns found in their own data, utilizing the open source Vollmer HRV Matlab add-in. The learnings from this type of hands-on activity are numerous: students learn how sensors capture physiological data from their own bodies, how to apply the concepts learned in the course, how to interpret the graphs, and explore why activities such as yoga and meditation are effective in lowering stress by increasing HRV. This is a compelling, relatable, and memorable active learning intervention.

Flash-lab Example 4: ***EMG Analysis of “hands-on” finger muscle activation***: This activity is part of a week-long activity in collaboration with Delsys Inc., in which students collect and record electromyographic (EMG) signals from their own fingers. Students learn about characteristics of EMG signals in time and frequency domains and what they indicate. Students process and analyze their individual EMG signals and evaluate the condition of their finger muscles (activated, fatigued, etc.). The activity concludes with students extracting relevant features from their EMG data and evaluating the results. This is a very well received hands-on learning opportunity for the students where they apply signal processing techniques learned in class to their own EMG data. This is typically a highlight of the course.