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Undergraduate curricular development at the Electrical Engineering/Music interface at Union College

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ABSTRACT

Curricular development at the interface of Electrical Engineering and Music will be described, with a focus on the pedagogical use of audio and acoustics to reinforce basic fundamentals in Electrical Engineering. The effort, which has taken place over more than a decade, seeks to support the foundation provided by the traditional, rigorous engineering curriculum at Union College, an undergraduate liberal arts college in upstate NY. A related specialized research laboratory - Phasor Lab - is located in the Peter Irving Wold Science and Engineering Center at Union.

1 Introduction

The long and storied history of the interactions between music and science[1] and the related seminal works such as Helmholtz *On the Sensations of Tone* [2] form a beautiful heritage and foundation for explorations at interfaces therein. Within the pedagogical realm, the graduate course on Acoustics from the perspective of Electrical Engineering taught by Prof. Amar Bose and the Physics & Music course developed by Prof. Saul Perlmutter at U. C. Berkeley have inspired many. One can acquire a sense of the diversity of approaches and the range of programs that exist for folding material related to audio and acoustics into academic structures of different overall size, proportion and organization through courses of study at the CCRMA at Stanford University, Penn State, Purdue, the University of Rochester/Eastman School of Music, the University of Hartford, NYU, Georgia Tech, Brigham Young University, the University of Cinncinati, McGill University, MIT and other institutions along with other useful resources such as[3, 4, 5, 6, 7].

Here, we will describe curricular development in support of an Electrical Engineering program that makes use of audio, acoustics and music in a variety of ways. The primary objective of this pedagogical development is to supplement and reinforce the teaching of fundamentals of Electrical Engineering at the undergraduate level. A specialized EE/Music research laboratory - Phasor Lab - was proposed and in 2011 came on-line as part of the Peter Irving Wold Science and Engineering Center. The lab was designed by the architectural acoustics firm, Walters-Storyk Design Group, with specifications simultaneously appropriate for both scientific work and for the performing musician.

The curricular development has been in progress for nearly fifteen years. The course development began with an advanced Electrical Engineering elective on sound and electrical engineering and a laboratory module that was incorporated into a sophomore circuits course that used music to help develop intuition about Phasor analysis. The material has expanded since then into several specialized courses and modules designed

for different points in the engineering curriculum.

The courses have been implemented in the context of a small liberal arts college with engineering that has a total undergraduate population of approximately two thousand students across all disciplines. We have connected the curriculum with the liberal arts side of campus through a suite of interdisciplinary course collaborations that generate a plethora of opportunities to reinforce core engineering fundamentals. Students from across campus have also performed undergraduate research projects and ideas for General Education spinoffs have been tested over time on liberal arts students and through the ID course collaborations.

The courses will be described below in order of appearance in the Electrical Engineering curriculum.

2 First year practica

Two practica were designed as part of a series of thematic ten week experiences for first year students. There were 22-25 students enrolled in each practicum. Students attended a weekly evening two hour lecture and up to seven one-hour small group sessions were run during the week for hands-on time with instrumentation.

The first ten week practicum (ECE-011) was developed and co-taught with an Electrical Engineer working in industry - Prof. Emad Andarawis from GE Global Research. It was offered right after construction of the Wold Science and Engineering building was completed, and leveraged the excitement and curiosity about the newly opened Phasor Lab by including architectural acoustical characterization tests (NC rating, reverberation time, etc.) along with photographs taken during the construction in order to increase a sense of appreciation in the students for the work performed by the members of architectural acoustics firm, Walters-Storyk Design Group, who designed the space. In addition, the first year students completed some traditional laboratories (building audio amplifiers, simple loudspeakers).

The following year, EMPAC audio engineer Prof. Jeff Svatek joined us to develop and teach an audio engineering-themed practicum. He incorporated a variety of active experiences for the first year students along with lectures. For example, in one exercise, Prof. Svatek brought in three speakers, whose horns each had different dispersion patterns. Full frequency material was played, and the students, armed with copies of the dispersion, walked around the lab and tried to guess which speaker was which. In another listening-based exercise, students learned about equal loudness curves. Other lecture topics and demos included a background on microphones (types and pickup patterns), the Haas effect, acoustical properties of rooms, absorption coefficients of different materials, the interaction of a loudspeaker system with the acoustics of a room, early reflections, and how all these things affect speech intelligibility. The course culminated in a talk that tied together the concepts from the different labs and showed where they appear in practice through a slide show on his professional experiences and career path as an audio engineer. For practical reasons, coverage of small group hands-on exercises Prof. Svatek developed was provided by combining the instructors from the two practica into a three-person team with one audio engineer and two EE's, and the EE's offered perspectives from time to time to alert the first year students to ways that the audio engineering demos could help them develop intuition about basic concepts they would be seeing in future, traditional EE coursework.

3 Modules for core courses

Laboratories and demos involving sound have been developed for several core EE courses, and take a cue from the act of careful listening to sound that is an artisan practice for professional audio engineers [8, 9].

3.1 Listening exercises in core EE classes

A laboratory was developed for the first sophomore analog circuits course (ECE-225) to teach Phasor analysis, RC circuit design and operational amplifiers. Exercises focused on connecting the graphical representation of Phasors with the time domain representation, guided design of an RC filter in the frequency domain and implementation of an op amp summer. Students both viewed and listened to the low pass filter's frequency response characteristic. They subsequently added noise to music, and listened to the filter output for different design choices. This module has been in use in the course for close to fifteen years.

In the sophomore digital signal processing course (ECE-241), prior to any theoretical treatment, students are challenged to predict the Nyquist theorem only by listening to signals. Students note the sampling frequency at which they can detect audible sound degradation as well as all other observations of changes in

sound quality. Using the 'just in time' strategy, the theoretical material is then started in lecture with computation of the normalized and alias frequencies for sinusoids, followed by impulse sampling of a signal with finite bandwidth. Upon returning to lab, students examine their signals in the frequency domain and are asked to explain all prior observations, including why some signals were better suited for aurally detecting the Nyquist rate than others. A guest lecture on audio engineering in ECE-241 by Prof. Svatek on tuning a room has also provided examples of time and frequency domain, linear phase, and other concepts linked with class material for this course.

3.1.1 Interdisciplinary lightning

Short interdisciplinary interactions, nicknamed 'interdisciplinary lightning', connect courses to generate a new problem or project that requires the expertise of both groups to address. Keeping the interaction short and somewhat non-perturbative makes the exercise more practical for the collaborating faculty members and allows the course pairings to be rotated rapidly. Opportunities to deepen understanding of core material are cultivated.

The digital signal processing course, ECE-241, has a required interdisciplinary team project. One year, the students recorded the performance of a choir on tour from Puerto Rico - Coro de la Universidad del Turabo - and filtered some rather prominent noise peaks from the recording. They had also convolved prior recordings of the choir with the impulse response of Union's Memorial Chapel. The exercise was planned in advance with the choir's musical director, Prof. Daniel Alejandro Tapia Santiago, who helped translate as the students explained their convolution projects to the visiting choir members. Another year, ECE-241 students compared impulse responses of different venues on campus and were joined with Union's Camerata Singers, conducted by Prof. John Cox, as they performed the same work in each venue for comparison. ECE-241 students explored whether DSP might be used to identify poetic devices in collaboration with a class studying Romantic poetry through exercises co-developed with Prof. Andy Burkett from Union's English Department. They also made binaural recordings of the English students reading poetry, which has intriguing possibilities for them as a performance format.

Although many of the collaborations have involved Electrical Engineering and music, the approach is readily transferrable, and has also been used to train students learning about the physics and operation of nanoscale microscopy instrumentation[10]. Another collaboration took place with Biology colleague, Prof. Rob Olberg, whose neurobiology class provided electrophysiological signals that needed filtering.

4 Advanced electives

4.1 Advanced course on synthesizing core material

One advanced elective course, entitled, 'Engineering Acoustics,' is in fact intended to provide students with critical exercise in synthesizing material learned across core courses in the sophomore and junior years. Students become used to studying material that is limited to a few sections at a time in a single textbook that are covered in a predictable order, but have less opportunity to practice connecting material across different courses. In ECE-370, audio and acoustics is used as a platform for defining a longer scale, guided project that requires students to refresh and connect material from the core courses in circuit theory, signal processing, systems and electromagnetics while absorbing the new concepts. In the first half of the course, a group term project is defined that requires the students to utilize selected material across these courses. In the second half of the course, they reinforce these skills by completing two take home exams extracted from material in the peer reviewed literature that span similar topics.

One group project for this course has revolved around setting up an acoustical measurement in a historical building on campus cast as a mystery about the building. Asking questions about proper interpretation of the incoming data and brainstorming about next steps has permitted concepts ranging from phasor analysis to frequency resolution and zero padding to occur quite naturally in the context of a single project, but in a randomized order with respect to coverage of related material in prior courses.

The individual mini-projects and presentations in this course, which has been evolving since its first offering in 2004, are a lighter component of the course, and the project topics have ranged widely, from musical acoustics (violin harmonics, chaldni patterns), sonification, music synthesis, the acoustics of tennis, psychoacoustics for film studies applications, measurements on propellers and fuel injection engines, to sound and

vibration tests for nanoscale microscopy instrumentation. One student, who had a black belt in Tae Kwon Do, recorded herself and a friend playing the Game of Thrones Theme as a saxophone duet, broke firecracker boards at various positions around a binaural head, and experimented with spatially distributed musical rounds formed through convolution with the original audio signal.

4.2 Advanced course based on analogs

A second advanced engineering elective course, entitled, 'Phasors, Waves and Music,' makes use of analogs between audio/acoustics and Electrical Engineering to teach Electrical Engineering concepts. Mathematical forms and concepts that are important elsewhere in the EE curriculum are reinforced using selected examples from musical acoustics, and exercises on the physical interpretation and visualization of these forms are emphasized in this context. ECE-369 reviewed circuit theory, and covered in detail telegrapher's equations, transmission line theory including Smith Charts, and waves with homework at a mathematical level that would be typical for a junior or senior level course in electrodynamics. The course used musical acoustics to help build intuition for these concepts through examples of transmission line theory applied to the modeling of musical instruments. Transverse waves on a string and calculation of resonant modes were covered in detail. Some material that would help students in advance of an antennas course was also covered, as well as instrumentation for experimental characterization of musical instruments, such as the laser vibrometer.

This course in its first offering was co-developed with Prof. Yu Chang, also from the ECE Department, and attracted musicians from five majors who had strong mathematical backgrounds. The course oversubscribed the first day of registration. With such a population, it becomes possible to weave thematic material into the course that is of particular interest to musicians who wish to improve their performance skills or understand their instruments from a different perspective. Students created videos demonstrating special effects on their instruments (organ, flute, saxophone, guitar, voice) for use in class, for example for the module on boundary value problems for transverse waves on a string. There was a History of Electrical Engineering thread to the course, a visual emphasis (i.e. Lissajous figures, Chaldni patterns) and we occasionally donned a purely musician's hat and linked J. S. Bach or Steve Reich to the course material.

5 Undergraduate projects

Undergraduate projects and theses have been performed by students across campus, ranging from Lissajous figures applied to musical temperament (Physics major) and application of audio techniques to monitoring electrical transformers (ECE major) to auralization of concepts in mathematics of music translated from ancient Greek texts by a premed/Greek major, after she completed a thesis with Classics Department faculty member Prof. Stacie Raucci. Students have performed unconventional experiments that deliberately couple audio signals into an atomic force microscope (AFM), and also converted aspects of the AFM operation to sound. One Political Science major studied violin harmonics with Musician of Ma'alwyck founder Ann Marie Barker Schwartz, and characterized her execution of the harmonics before and after the training. An ECE student compared her vocal spectral characteristics when singing opera/contemporary music during lessons with opera singer Corine Salon.

6 Music collaborations and outreach

We have embraced the philosophy of lifelong pursuit of music as an integral element of a career in science and engineering. Inspired by Prof. Mildred Dresselhaus, we have used chamber music sightreading in Phasor Lab as a way to bring students together with professional mentors in science and engineering. We were profoundly grateful to have her as a guest along with musicians from the community for chamber music and mentoring of Union students and Schenectady area middle and high school students in the STEP program over this time period. We have supported, as much as feasible, some instrumental practice time in between engineering classes.

Encouragement for students to maintain depth in both engineering and music has been approached through example - recitals outside of the regular engineering faculty obligations, accompanying students and choral groups, and providing impromptu music coaching for double majors in the laboratory. As another mentoring format, we have invited professional engineers to give 'double features' - an engineering colloquium and a joint full length chamber music recital in the same visit.

Phasor Lab is the home base of the Heavenly Voices Gospel Choir (HVGC) and their musical director, Prof. Lynny Walters. The choir rehearses regularly amidst the scientific instrumentation on a Yamaha Motif XF8 setup, acquired through a collaboration with the Union's CDO, Dr. Gretchel Hathaway. Prof. Walters, also teaches music practica in the lab and has created unique experiences in musicianship for students, both those majoring in engineering and from across campus.

Over time, the musical life of the laboratory has emanated from a variety of genres, from Gospel music to classical opera. We have performed binaural recordings of the Gospel choir, an R&B band, concerto competition winners, the Union chorale, and chamber music in Phasor Lab and other venues on campus.

A neuroscience major, Kabir Chabra, organized a year of weekly Music Therapy sessions in Phasor Lab for adults with cognitive disorders, such as autism, aspergers or down syndrome, in collaboration with Schenectady ARC: 'Music with ARC.' He has been joined regularly in this volunteer activity by some of the members of the all-student band, No Wonder, who often rehearsed in the lab as well.

We have worked closely with the Kenney Community Center's STEP Program (Science and Technology Entry Program). A workshop format that pairs a professional musician/Electrical Engineering faculty member to co-teach a module on math and physics that springboards off of their interest in music was piloted by Gospel pianist Tyrone Hartzog and the author, and delivered as part of the STEP program. Thanks to efforts from the Kenney Center's Director, Angela Tatem, these students attended a packed concert the previous evening at Proctor's Theater at which he was the lead keyboardist. In other outreach activities, we have supported multi-week summer projects, and created ice-breakers and a number of other one-two hour workshops for STEP and other K-12 programs.

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