

USING MUSICAL INSTRUMENTS AS AN ENGINEERING EDUCATIONAL MEDIUM

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Abstract $\frac{3}{4}$ At Tufts University we have developed and implemented a curriculum in Musical Instrument Engineering (MIE). This program includes both a concentration certificate for the mechanical engineer and a minor for those majoring in other degrees. By using musical instruments as an educational medium, we are teaching the fundamentals of engineering through a familiar and non-threatening subject. Further, the use of musical instruments as a pedagogical tool allows central engineering principles to be more intuitive and accessible to students of all disciplines. This creates a unique situation, where engineers and their liberal arts counterparts work side-by-side solving problems and developing creative solutions. Thus, both groups benefit from a diverse classroom population.

The program implements three major facets of engineering education; lecturing, project design and development, and scientific research. Because of the familiar subject matter, this multi-faceted learning experience is not only more enjoyable, but the concepts become instantly applicable and are internalized more quickly.

Index Terms $\frac{3}{4}$ Education, Engineering, Instrument, Musical.

INTRODUCTION

Unlike most subjects and research topics found in today's engineering schools (such as particle laden turbulent flows [1] or chemical-mechanical planarization [2]), nearly all people have had personal experiences with music and musical instruments. With musical instruments as the educational focal point, the subject matter is instantly recognizable, accessible, and enjoyable. Further, in offering an educational medium that is approachable and intuitively understandable by most students, we make many core concepts of engineering easier to learn. On a larger scale, both the minor and concentration certificate give an education with an engineering focus, as many engineering principles can be applied directly to musical instruments. For non-engineers participating in the program, many technical topics can be applied to musical instruments, providing motivation and increasing interest in course work. Despite the potential in this approach to teaching engineering concepts, surprisingly few universities study the physics and engineering behind musical instruments. Some instances do exist, such as Stanford University [3], Princeton University

[4], and Eindhoven University in the Netherlands [5]. Unfortunately, most of these programs give limited access to undergraduate students, and none offer a formal degree augmentation.

A BRIEF HISTORY OF THE MUSICAL INSTRUMENT ENGINEERING PROGRAM

The first instance of musical instrument engineering at Tufts was a freshman "half-course" titled "Design and Performance of Musical Instruments." Originally offered in the spring of 1994, the course was intended to pique the interest of students in engineering by teaching them principles of engineering using musical instruments as the educational medium. Although this course was geared toward budding engineers, it was open to and populated by liberal arts students and music majors as well. This course caught the attention of Steinway Musical Instruments, the parent company of Steinway & Sons Pianos and Selmer Musical Instruments. An alliance was soon formed and the Tufts School of Engineering began working on a variety of research projects for the two companies. These projects included the development of a manufacturing quality control system in the woodwind factory at Selmer, the acoustic effect of cryogenically treating trumpets, and the effect of temperature and humidity changes on grand piano actions.

The popularity of the course and the related research projects prompted the involved faculty (from the Mechanical Engineering, Electrical Engineering, and Music departments) to begin development of the Musical Instrument Engineering (MIE) program. The curriculum for this program includes both a minor and a concentration certificate in musical instrument engineering. The upper-classman course "Musical Instrument Design and Manufacture" was created at this time to act as the core class of the program. This course, along with the minor and concentration certificate, was approved in 1999 and originally offered in the spring of 2000. A related course, "Electronic Musical Instrument Design (EMID), was developed and offered in the fall of 2001. Also in the fall of 2001, Chip Jones was hired as the Director of the MIE program, giving the program full-time leadership for the first time. For the spring semester of 2002, both the freshman half-course and the upper-level course are being offered for the third time.

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MUSICAL INSTRUMENT ENGINEERING COURSES

Currently three courses have been developed and offered in the Musical Instrument Engineering program. The freshman half course, "Design and Performance of Musical Instruments" is part of a series of classes in the Tufts School of Engineering that is intended to present first year engineering students with an introduction to applied engineering concepts. In this class we are able to teach the fundamentals of vibrations, acoustics, wave theory, material science, and structural dynamics using a wide variety of musical instruments as focal points.

Currently, the structure of the course involves lecture and project development occurring in parallel. Each class period is evenly split between class-time and time spent in the Tufts Engineering Project Development Center (EPDC). For example, a class period may start with a lecture on wave propagation and reflection within pipes of various configurations. The students then move into the project center's workshop to construct simple flutes and recorders made from PVC pipe. Finally, the students are given a homework assignment requiring them to calculate the actual and theoretical frequencies of the scale of their instruments, comparing and explaining the discrepancy between the two sets of results.

In general, the instructor assigns the projects of the first half of the semester, with different assignments having varying levels of allowable interpretation. For the second half of the semester the students develop and build an instrument of their own design. These projects range from attempted replicas of instruments to completely original designs. Figures 1 and 2 show examples of these two approaches built for this class. In Figure 1 a student is shown playing her homemade violin. Figure 2 shows a concept instrument, "The Mandolitar," described as a cross between a mandolin and a guitar. The semester culminates with a concert, where each student is required to give a performance on his or her own instrument, playing an original composition.

The upper-level course, "Musical Instrument Design and Manufacture" is similar to the half course, but is more in depth. Instead of just touching on the subjects from a conceptual view, the higher-level math behind the theory is addressed and explored. All major instrument families are studied. More attention is given to material properties and their effect on instrument tone, and the subtleties of sound generation are explored more completely. Further, more is expected from the final projects, and all students conduct an acoustical analysis of their instruments in a sound room constructed specifically for musical instrument research. Projects from this class, a renaissance style lute and an alternative cello design, are presented in Figures 3 and 4 respectively. Finally, this course is augmented by a seminar series, where musical instrument researchers and industry craftspeople are brought in to give lectures and

demonstrations to the class. These seminars are also open to the entire Tufts community.



FIGURE 1
STUDENT PLAYING SELF-CONSTRUCTED VIOLIN



FIGURE 2
THE "MANDOLITAR," AN ORIGINAL DESIGN



FIGURE 3
RENAISSANCE STYLE LUTE

The newest addition to the list of Musical Instrument Engineering courses is "Electronic Musical Instrument Design," offered for the first time in the fall of 2001. Unlike the courses discussed above, this course is cross-listed as both an engineering class and a music course. Accordingly, the population of the class was essentially split evenly between students from the two schools. A major goal of the class is to have students re-think the interface between musicians and electronic instruments: while traditionally electronic instruments are controlled by a piano-like keyboard and/or groups of knobs and sliders, this class encourages students to develop new models of gestural control over musical parameters, incorporating an expanded vocabulary of physical motions. The structure of this course also combines lecture periods and project development. Students receive lectures and guidance on the interaction

between computers, software, and electronic musical instruments via MIDI (Musical Instrument Device Interface). In addition, the first half of the semester involves smaller projects, and then the term finishes with more ambitious group final projects. These projects have included a sound generating computer algorithm controlled by an “electric trumpet” and a device that mechanically tracked the position of a performer’s arm and hand to control pitch, timbre, and voice selection of a computer-based synthesizer.



FIGURE 4
STUDENT PLAYING ALTERNATIVE DESIGN CELLO

All groups contained both engineers and liberal arts / music majors, thus the two groups of students were fully integrated and benefited from each other’s strengths.

COURSE STRUCTURE OF THE MINOR AND CONCENTRATION CERTIFICATE

The MIE curriculum has two degree offerings, depending on the background of the participating students. The minor is offered to all students not majoring in Mechanical Engineering. In order to graduate with the minor, a student must successfully complete the following courses and requirements:

- Musical Instrument Design and Manufacture (ES 73)
- Dynamics and Vibrations (ME 37)
- Fluid Mechanics (ES 8) or Physics of Music and Color (Physics 10)
- Music Composition (Music 3, Music 4, or similar course)
- A practical musical instrument design experience such as a research project (ME 19, ME 92, ME 93, or ME 94), related internship (ME 99), or Museum School course (FAMB 82)

- Attendance at the monthly musical instrument engineering seminar series

Thus, any student with a strong mathematical background and an interest in music and musical instruments can participate. For the mechanical engineer, the concentration certificate is available. To graduate with the certificate, the student must complete all of the above requirements as well as the following courses:

- Acoustics (ME 136 or ME 139)
- Advanced Materials Science (ME 120 or ME 122)
- Advanced Vibrations (ME 137)
- Finite Element Analysis (ME 129)
- Technical Writing (ES 51)
- A related Senior Design project (ME 43)

Both the minor and certificate were designed to take advantage of existing courses wherever possible. Further, the requirements for the certificate run parallel to those of the BSME degree, allowing the student to satisfy the requirements for both simultaneously.

RESEARCH PROJECTS

In 1997, a diverse selection of research projects was launched at Tufts with the support of Steinway & Sons Pianos and Selmer Musical Instruments. These initial projects included the development of a quality control database inventory system for the woodwind production facility at Selmer, a study on the acoustic effect of cryogenically treating trumpets, and the effect of temperature and humidity on grand piano actions. The quality control system was implemented in 1998, the cryogenic trumpet project evolved from an undergraduate research project to a master’s thesis [6], and the piano action work continues on today, being conducted by a candidate for a masters degree in music. In addition to these initial projects, many more have been or are currently being conducted with the support of Steinway and Selmer. These include holographic imaging of vibrating musical instrument surfaces, visualization and direct measurement of air motion inside clarinets, and optical calibration measurements of piano actions. Corporate sponsorship has also come from Listen, Inc., a developer of loudspeaker quality control products. This project involves the detection of non-periodic noise in speakers. Projects have also been initiated by students, including spectral analysis of various flutes and a modal analysis of the vibration of Irish bagpipe reeds.

In every case, these research projects have been conducted by undergraduate students in whole or in part. Only the piano action study and the cryogenic trumpet project were conducted by graduate students, and both of these were initiated by undergraduates. Although the majority of students participating in these projects are

mechanical engineers, electrical engineers and music majors are also represented.

IMPACT ON STUDENTS' LEARNING

By giving engineers (as well as students of many other disciplines) a glimpse of engineering principles at work within the context of a familiar and enjoyable subject, students go on to view their prerequisite courses in a new light. Subjects such as calculus and physics become more relevant in the scope of the students' learning process.

Naturally, courses in Musical Instrument Engineering appeal to engineers with a musical or performance bent, and musicians with an interest in technology-as well as visual artists, dancers, and non-majors with interests in one or both areas. This merging of populations gives students in each discipline an understanding of and appreciation for those in different fields: engineers learn the structure and aesthetic of music and music performance, while musicians learn engineering principles and applications.

By offering courses such as these, our engineering program is able to attract students from a larger population, especially women in music and liberal arts programs, who might not otherwise feel comfortable in a conventional engineering course. Further, to have these experiences open to beginning engineering students gives them a practical, gratifying, and fun educational experience right away, hopefully motivating more of them to remain in or transfer into engineering programs.

METRICS OF SUCCESS

As is usual for the freshman Musical Instrument Engineering course, registration is at the maximum for the spring, 2002 semester. Student attendance for all classes is consistently high, and students regularly give these classes high marks on the end-of-the-semester evaluations. Enthusiasm and morale among the students in the courses is always high, and the effort applied to both the smaller projects and final instruments is staggering.

Although both "Design and Performance of Musical Instruments" and "Musical Instrument Design and Manufacture" are listed as mechanical engineering courses, both classes are highly populated by liberal arts students (25%), and engineers from other disciplines (25%). Likewise, only about half of the students enrolled in "Electronic Musical Instrument Design" were engineers. Thus all classes enjoy a high level of inter-disciplinary participation.

Student enrollment in the minor / concentration certificate continues to rise, with one student already graduating with the minor and two students slated to receive the certificate in the spring of 2003. Another 6 students are presently working toward the minor, and will be graduating over the next three years. Participation and interest in the degree programs are essential evenly split between men and

women. Enrollment in research projects is also on the rise, with 4 undergraduate students conducting research in the spring semester of 2002.

FUTURE DIRECTIONS

Presently, moves are being made to expand corporate sponsored research in order to match the increase of student interest in the program. Also, funding is being sought from the National Science Foundation to help support student initiated research and further develop the MIE program's curriculum.

Starting in the summer of 2002, we will be initiating an outreach program to local schools, giving 5th – 7th graders a chance to come to Tufts on a half-day field trip and have hands-on experiences with musical instruments while being introduced to the science behind them. This program is being offered with the support of the Bose Corporation. In the summer of 2003 we hope to expand this outreach program to include a week-long day camp, introducing grade-school and high-school students to the craft and science of musical instruments.

CONCLUSION

Student response to the program has been very positive, as measured by increasing year-over-year enrollment in the MIE courses and degree programs. Consistently high student evaluation scores is also testimony of our success. A constant stream of undergraduate research projects as initiated by both corporate sponsors and students themselves further attests to the accomplishments of the MIE program. Our corporate sponsors continue to be pleased with the results of our shared research projects, and their extensive support of the program is a concrete measure of our success.

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