Work in Progress: The Consumer Breathalyzer as a Model Design Project in Introductory Instrumentation

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Poul's research focuses on using novel instrumentation, detailed computational models, and quantitative descriptions of physical processes to gain a better understanding of human physiology. Many of his projects couple mathematical modelling with innovative instrumentation to improve our ability to understand and interpret measurements of complex biological systems, subject to the constraints of well-understood physical conservation and balance laws.

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Introduction

Biomedical engineering is a broad discipline, requiring the application of concepts from mechanical, chemical, electrical, and materials engineering to problems in medicine and biology. One of the most prominent ways in which these areas are brought together is in the development of medical instrumentation, designed to measure a property of the human body and report the result to a medical practitioner. Instrumentation poses a conundrum for the biomedical engineering educator: in order to make a plausible instrument, knowledge and skill from a wide range of disciplines are required, yet we cannot afford to wait to begin teaching it until after students have studied these other disciplines[1]. Thus, if early hands-on coverage of instrumentation design is desired in the curriculum, the design project needs to allow for enough abstraction of the biological, chemical, and electrical underpinnings of the desired measurement that the students can tackle the challenge with only the knowledge gained in a small number of introductory courses, while also engaging student interest to avoid turning the project into a make-work exercise.

In this paper, we describe the design project we use for second-year biomedical engineering instrumentation, BIOMENG 241, at the University of Auckland. In this course, students are asked to design simple breath alcohol detectors for consumer-level use. We will provide the context for the project in the biomedical engineering curriculum, describe the structure and learning objectives of the course, present the details of the project itself, and conclude with some of the student feedback and achievements from the first two years of the current instrumentation course format.

Degree program context

At the University of Auckland, introductory biomedical engineering instrumentation is taught during the second semester of the second year. First-year students take a common set of courses across all degree specializations, covering design (engineering drawing), mechanics, biology and chemistry, calculus, computer programming, materials science, and electronics. During the first semester of the second year, biomedical engineering students study cellular biology, multivariate calculus, numerical methods, and solid mechanics. In addition to instrumentation, during the second semester students also cover tissue engineering, organ systems, and engineering communication. Students taking BIOMENG 241 have a broad but shallow base of engineering knowledge; this course constitutes their first exposure to open-ended design problems.

Course structure

BIOMENG 241 is formally titled "Instrumentation and Design," and is built around learning objectives that cover both fundamental concepts in signal processing and circuit design and practical engineering design tools and processes. Key learning objectives explored and assessed via the project include the ability to design simple electromechanical instrumentation, compose written reports about the design process, prepare group oral presentations, utilize electrical and mechanical computer-aided design, and create instrumentation software in LabVIEW. These, in turn, rely on students having achieved a set of learning objectives related to electronic circuit theory, operational amplifiers, and electronic components.

BIOMENG 241 is organized with two lectures per week of one hour each, plus one two-hour laboratory session per week. Lectures cover the design process, passive electronics, operational amplifiers, filters, digital sampling, component selection, ethics, and safety. Laboratories cover brainstorming, electronics instrumentation, soldering, operational amplifier circuits, aliasing, and quantization. Project work is performed outside scheduled class times, with the exception of final presentations held in the last laboratory period. The design project directly determines 25% of the final grade, with the final exam determining 50% of the final grade and other in-class assessment (mid-term test, homework assignments, and laboratory exercises) constituting the remaining 25%. A portion of the final exam (10% of the course grade) assesses students' individual achievement of the learning objectives associated with the design project.

Design project

Students are assigned to groups of five or six members, and prompted to design a portable breath alcohol detector for use by pub patrons. It is explained that they are part of a company that has identified the MQ-3 alcohol gas sensor[2] as appropriate for the task at hand, and their goal by the end of the semester is to construct a working alpha prototype. Their prototype is required to be housed in a consumer-friendly 3D-printed case, use an operational amplifier circuit on a printed circuit board of their design to buffer and filter the signal from the sensor, and use a data acquisition unit and a LabVIEW program to interpret the measurement. They are given a kit of parts including an alcohol sensor, a breadboard, a multimeter, a USB connector, and a National Instruments USB-6002 data acquisition unit. Staff also supply a wet breath alcohol calibration system, so that students have a reference breath source. The cost of consumables (including the PCB) is approximately $30 per group, not including 3D printing costs.

The project is scheduled closely with the lectures and laboratories so that students have been exposed to content relevant to each phase of the project before they need to complete it. Key project milestones include a short progress report due at the end of the 6th week of the semester, for which the team should have a mechanical design for the breathalyzer case and an electrical circuit schematic; a non-assessed deadline at the end of the 8th week for the submission of Gerber files for PCB fabrication; and a final presentation and report due at the end of the 11th week, at which students are expected to show results obtained using an assembled prototype. To fit with this schedule, the early lectures and laboratories cover design tools, such as brainstorming and concept selection, as well as software tools such as SolidWorks, LabVIEW and Altium needed to undertake the design. The course then covers basic passive electronics and operational amplifiers, both in the lecture and the laboratories. Our goal is to ensure that the knowledge required to complete the project is covered in class by the end of the 7th week.

The project is assessed by means of an individual project notebook and group-assessed progress report, final report, and final presentation. The project notebook is assessed twice during the semester, to ensure that it is being used and contains information with an appropriate level of detail. The reports and presentation are assessed according to a standard rubric, with a peer assessment component for the presentation. We expect students to develop, from the prompt and through literature search, an appropriate set of specifications for their breathalyzer, a design capable of meeting those specifications, and evidence to show that their design does so. We do not assess the project on device performance, as the learning objectives are concerned with the students' ability to follow the design process, not their ability to build accurate breathalyzers.

Results to date

DESIGN OPTIONS	Screen	Light	Vibration	Sound
Cost	S	+	+	S
Production	S	+	-	+
Technical Difficulty	S	+	S	+
Size	S	S	S	+
Ease of Understanding	S	+	-	-
TOTAL	S	4	-1	2

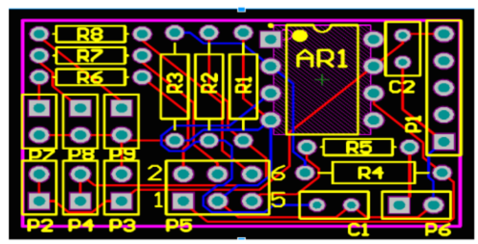

Figure 1 (left): An example of a student-generated Pugh chart examining techniques for notifying the user they have exceeded the legal breath alcohol limit.
Figure 2 (right): An example student-designed printed circuit board.

Figure 3: Two examples of complete student-built breathalyzers; the one on the right is demonstrating detection of breath alcohol above the legal limit.

This project has been run twice thus far: in 2014, with 44 students, and in 2015, with 35 students. Each year, all groups were able to make a working sensing circuit, capable of discriminating between different alcohol concentrations, as well as an appropriate case. Examples of student work are shown in figures 1-3; figure 1 demonstrates student mastery of Pugh concept selection, and figure 2 shows a size-minimized PCB layout. Figure 3 shows two different case designs, each of which houses a PCB; the wires connect to the data acquisition unit. The team on the left emphasized the ease of holding the device, while the team on the right focused on miniaturization, using figure 2's PCB. While both these groups used non-inverting buffer amplifiers for signal conditioning, others used level-shifted inverting op-amp circuits.

Student feedback is positive, with students valuing the project highly for its contribution to their understanding. Student performance (as assessed via overall grades) has remained stable through the introduction of this project. Work is ongoing to determine the impact of this course more precisely, and to determine the best sequence of lecture content to complement the project.

[1] Sheppard, S. D. and Jenison, R. (1997). "Freshman engineering design experiences: An organizational framework." International Journal of Engineering Education 13(3): 190–197.

[2] SparkFun Electronics. https://www.sparkfun.com/products/8880 Accessed July 21, 2014.