# Device-Based Learning for Biomedical Engineering

Ezra Kwok and Anthony Chan

*Abstract*—**Biomedical Engineering education has increased in popularity for the past two decades. New programs have been developed to prepare students for this emerging field of study. With its highly multidisciplinary and interdisciplinary nature, biomedical engineering is able to better prepare graduates for a engineering career that incorporates aspects life sciences such as medicine and biology. The University of British Columbia established a graduate level biomedical engineering program in the fall of 2006 after arduous consultations and an extensive survey process with the industry. This new program employs a device-based approach to teaching the life science components including anatomy and physiology. Feedback from industry sponsors and practicing biomedical engineers favour this UBC approach. A graduate survey was performed in 2011 with overwhelming endorsement to this device-based approach of life science education.**

*Index Terms*—**Biomedical engineering, problem-based learning, engineering education, medical devices.**

## I. Introduction

The higher demand for advanced technological developments has made biomedical engineering an important educational field in the past two decades. Similar to many universities that have a formal educational program, the University of British Columbia (UBC) has established a graduate Biomedical Engineering program that meets this need, Although the program started in the fall of 2006, this UBC initiative dates back several decades ago when a few faculty members in the Department of Electrical Engineering became involved in medical device development, and the Faculty of Graduate Studies offered a Master of Engineering in Clinical Engineering. The combination of a traditional engineering program, with limited education in medical and biology, and the ever increasing interdisciplinary and multidisciplinary field of biomedical engineering, UBC's program faced a number of challenges in its current curriculum. Joint effort with the industry leaders have helped shaped UBC's Biomedical Engineering program to be one that includes applied anatomy, physiology and pathology in its curriculum, and where practicing medical clinicians directly contribute to the education of engineering students with limited life sciences backgrounds.

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## II. UBC Biomedical Engineering Curriculum

### A. Industry Survey

The role of the university as a higher learning institution which imparts knowledge, passes on experience, generates ideas, and expands on the wealth of human intelligence is being challenged by the goal of employability. As more and more graduates stress on the need to be employable, a successful program holds a new perspective where pure intellectual learning takes a back seat to the collaboration effort with industry to produce marketable graduates. Biomedical engineering, with its direct implications on human health and well-being, has responded by directing its educational focus to be more healthcare specific and industry savvy. An industry survey of the local biomedical companies in British Columbia was conducted in early 2006 to help UBC gain a better understanding of this shift in paradigm. The survey included a set of questions about the type of employees, the required training and skill set for successful career development in the local biomedical industry. Some objectives included:

- Determining the minimum level of education required to be hired into the company;
- Identifying what components should be included in a biomedical engineering program;
- Determining what type of biology background students should possess to be employed in a specific biomedical field; and
- Clarifying whether strong research skills are needed for entry-level positions.

Senior staff including engineers, managers and, in some cases, company CEO's were surveyed, and although the response rate was approximately 20%, the respondents provided interesting perspectives relevant to the design of the UBC program.

### B. Survey Results

Fig. 1 shows the breakdown of the companies involved in the survey. Medical device companies account for the majority of the survey pool, but the percentage does not reflect the actual ratio of companies in BC, nor does it reflect the corresponding revenue for each sector. Most respondents are affiliated with companies where their main research or development facilities are located in BC, or employing a staff of less than 50 on site in BC.

The educational background of the staff in most surveyed companies hold technical diplomas and bachelors degrees as opposed to graduate-level degrees. The survey asked one key question: To identify the undergraduate engineering discipline best suited for employment. The breakdown of the companies' preference in terms of prospective employees' backgrounds is shown in Fig. 2. Not surprisingly, the medical

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device companies predominantly hire electrical or mechanical engineers. But interestingly, after discussions with company representatives, it was noted that most companies prefer not to hire undergraduates with degrees in biomedical engineering. Their reasoning was that biomedical engineering is such a multidisciplinary field that they believed biomedical engineers should have a primary focus in one fundamental engineering discipline before gaining additional specialized training in biomedical engineering.

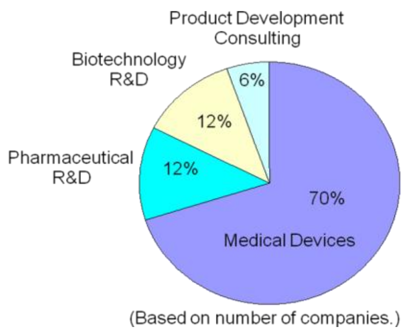


Fig. 1. Percentage of companies involved in survey.

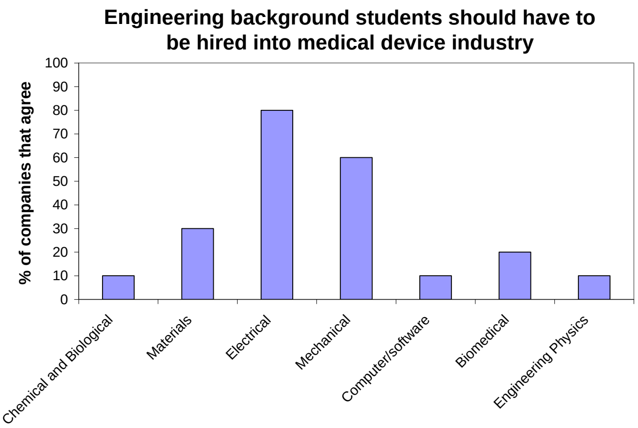


Fig. 2. Engineering background for employment.

Another major finding was the preference of many companies to have graduates with early exposure to the regulations and standards governing the biomedical or medical industry, as well as good business management skills. They found this to be an asset. Since the whole healthcare industry is tightly regulated, any viable project development has to meet a particular industry standard in a cost-efficient manner. An engineer with knowledge of the standards and regulations will be able to contribute more readily and efficiently to the company. One of the respondents went as far as to say that his particular company will not hire a biomedical engineer with no training in regulatory standards. Finally, all there was a general preference for students to have at least some training in life sciences at the university level as well as some exposure to the clinical environment.

### C. Final Curriculum

The UBC Biomedical Engineering program, in light of the industry survey and consultation from different schools and advisory bodies, established a graduate curriculum requirement that includes three major components: core biomedical engineering, industrial practice of biomedical engineering, and clinical life science. The core biomedical engineering component encompasses a wide spectrum of courses that draw from the expertise of current faculty research within the different biomedical engineering areas. The industrial practice component includes standards and regulations as well as engineering management subjects relevant to the local biomedical industry in BC. The clinical life science component poses a challenge especially to many mainstream engineering programs as many undergraduate engineering students have limited to no life sciences backgrounds. Some have not taken any biology courses in high school. A number of schools in Canada have recognized this limitation and broadened their curriculum to include some life sciences courses. However, many students are still restricted from taking full biology or biochemistry courses in university because they lack the prerequisite high-school biology. In addition, many of the university-level life science courses lack applications appropriate to engineering students whose problem-solving skills are in the context of engineering design and development. The UBC Biomedical Engineering program has addressed the aforementioned challenges through the development of a set of new courses including a unique, applied life sciences course for its students.

## III. Life Science Curriculum

### A. Curriculum Approaches

The principal author has visited several engineering schools that offer similar biomedical engineering programs. A common theme that has surfaced during discussions is the difficulty in introducing a significant life sciences component to an already-heavy engineering curriculum at the undergraduate level. Most schools have elected to have students enroll in pre-existing courses with students from different disciplines - this is usually the least expensive approach but presents the problems of relevance and appropriateness for engineering students lacking prerequisite knowledge of biology. Engineering students find themselves in a highly competitive environment when these courses are also subscribed by pre-medicine, pre-dentistry or pre-pharmacy students. (One school outside of Western Canada chose to evaluate engineering students with their own set of assignments and examinations in order to ensure a reasonable average for the group.) An additional problem with pre-existing courses is that the breadth and depth of knowledge, as attested by many practicing biomedical engineers who have completed those courses, is more geared towards science students intending to pursue advanced degrees in the same subjects. An alternative approach being used by some schools in Canada is a survey-style course for engineering students. Such survey courses attempt to cover a broad range of topics in biology, biochemistry, physiology and anatomy at a superficial level.

At UBC, the decision was made to develop a stand alone course for biomedical engineering students that would present general principles of human anatomy, physiology and pathology relevant to the practice of clinical medicine. While it needed to take into account the student's limited life sciences background and take advantage, where possible, of their pre-existing engineering knowledge and problem-solving skills, its relevance to the field of biomedical engineering must not be overlooked. In addition, it would have to be taught across a single term. With these goals in mind, UBC has developed a medical device-based course in human anatomy/physiology/pathology for the Biomedical Engineering curriculum.

### *B. Device-Based Learning*

In teaching human anatomy and physiology, the organizational scheme utilized must be appropriate to the curriculum in which the anatomy/physiology course is taught. A traditional regional approach to the study of anatomy, enhanced by cadaver dissection, is critical in surgical training, for example. A systems approach, perhaps the most often followed, lends itself to the presentation of important structural/functional relationships. With advancements in medical imaging, sectional anatomy courses allow students to recognize significant structural relationships as presented in a two-dimensional context. And in the past few decades, pioneered by McMaster University in 1969 [1], problem-based learning (PBL) has been widely introduced into medical school curricula to ensure that the basic sciences component (including anatomy and physiology) is relevant to, and integrated into, the training of medical professionals [2]. The evaluation of this approach at the University of Hong Kong's medical school also found it beneficial to even high school graduates entering medical training [3].

Given the emphasis in engineering curricula on the identification/analysis of problems and process of their resolution, a PBL approach to instruction in anatomy/physiology was seen as being particularly attractive. The concept of centering medical training around clinical scenarios and directing students to the principles of basic science underlying those scenarios is seen to have great merit. It is what some researchers call an anchored instructional design model. "At the heart of the [Anchored Instruction] model is an emphasis on the importance of creating an anchor of focus that generates interest and enables students to identify and define problems and to pay attention to their own perception and comprehension of these problems" [4]. Sherwood and Klein present evidence of traditional educational methods often producing 'inert knowledge' which, acquired previously in one domain, cannot be accessed when needed in a different context. They propose that an anchored instructional design can be used to "create macro-contexts for students in order that knowledge learned might be used in new settings rather than remaining inert," and points out that "concerns about student's ability to use knowledge in new situations have influenced the research and development undertaken on project- and/or problem-based learning in scientific education" [5].

Appreciating the merits of the anchored instructional component of the PBL medical curriculum, the anatomy/physiology/pathology component of the UBC Biomedical Engineering curriculum has been designed using the same model but with a different 'anchor'. The focus in this course is medical devices rather than clinical scenarios. Following a brief description of a selected medical device, students are introduced to the anatomy/physiology/pathology relevant to the design, operation and significance of the device to medical practice. The teaching philosophy is to guide students in developing the skills and approach to explore and analyze a body system and reverse-engineer the device so that the "not-so-exciting" physiology and anatomy will "come alive" while students are scrutinizing the devices. It will also equip students for a life-long learning practice especially important to the field of medicine [6].

### *C. A Device-Based Anatomy, Physiology, and Pathology Course*

Course planning began with the compilation of a list of classes of medical devices commonly encountered in clinical medicine. Devices were grouped according to relevant anatomical/physiological system, and those that would serve to anchor the course content were selected. Priority for inclusion of a device, or class of devices, was given to those available for hands-on demonstration. Limited to a single-term course, the decision was made to sacrifice breadth for depth of topics covered. Body systems chosen for presentation were those that included a range of devices (diagnostic as well as therapeutic) and relevance to multiple core engineering disciplines (Electrical and Mechanical, for example). An additional factor considered was whether or not underlying anatomy/physiology/pathology topics covered could take advantage of engineering knowledge previously attained, which could then be transferred into the context of the 'human machine'. The resulting limited breadth of the course is summarized in Table I.

It was crucial that selected topics be covered in sufficient depth so that students would gain an appreciation of the anatomical/physiological/pathological principles that underlie the design, operation and clinical value of medical devices. The goal was to develop concepts rather than present details. Common threads were woven through the course to help meet this goal. As an example, consider the following course content anchored to the electrocardiograph. Prior to encountering the Heart under the heading of the Circulatory System, students were introduced to the cell-tissue-organ-system continuum of function units through a discussion of the biopotentials displayed by individual cells. A unit on integument, which focused on the skin as an interface, helped prepare students engage in a discussion of the recording of electrical potentials at the body surface. Under the Heart subheading, the electrical events of the cardiac cycle could then be related to the cellular events of the cardiac myocyte and the structure of the skin to the surface electrocardiogram. The addition of information regarding specialized pacemaker cells and conductive pathways within the heart led to a discussion of the physiological basis of the electrocardiogram. A supporting tutorial on cardiac arrhythmias and a hands-on opportunity to record a 12-lead electrocardiogram placed the anatomy/physiology in a clinical context.

### *D. Overall Student/Graduate Satisfaction*

The evaluation of this course using the standard UBC course evaluation forms indicated that all students were extremely satisfied with the course and the overall graduate program curriculum. A few students continued on to advanced courses in human physiology, and all of them felt that they were very well prepared. In fact, every student felt that the device-based learning was significantly more interesting, useful and practical than the traditional teaching style of human physiology and anatomy.

TABLE I: TOPICS INCLUDED IN THE DBL CURRICULUM

| Devices | Body system |
|---|---|
| Biopotential Electrodes, EEG, EMG, ECG | Cytology integument |
| ECG, Pacemakers, Defibrillators | Circulatory - Heart |
| Sphygmomanometer, Flowmeters, Doppler | Circulatory - Vascular |
| Cell Counters, Hematocrit, Plasma Volume, Electrochemical Sensors, Blood Gases | Circulatory - Blood |
| Spirometry, Ventilators | Respiratory |
| Renal Dialysis, Urinalysis | Urinary |
| ENG, EEG | Nervous |
| Prostheses - Internal/External | Musculo-Skeletal |
| Endoscopes | Gastrointestinal |

To collect feedback from those who have completed their study, a survey was performed in 2011. All graduates who took the course were invited to complete an online survey. The survey contains 8 multiple choice questions. Graduates were invited to the survey by emails. A reminder email was sent to each graduate one week after the initial survey invitation. Table II lists the questions in the survey. Fifty two responses out of 96 students (54.2% response rate) were received within the 2-week survey period. Below is the summary of the survey.

The responses from the graduates to question 1 are 2 are shown in Fig. 3 and Fig. 4 respectively. The respondents were asked to choose from 5 answers ranging from "strongly agree" to "strongly disagree" for each of the questions. Fig. 5 summarizes the perception of the graduates on this device-based learning approach. The results show that most agreed that the device-based approach helped them in learning anatomy/physiology/pathology, and captured their attention. The right column in the table records the percentage of graduates who strongly agreed or agreed to the statements in the questions. Fig. 6 reports the responses when the graduates were asked about which type of course activities were important. It is interesting to note that, among all activities, "lecture" was still considered the most important component of the course.

TABLE II: QUESTIONS IN GRADUATE SURVEY

| | |
|---|---|
| Q1. What was your degree of study when you were taking APSC (BMEG) 452/530 | Agree |
| Q2. What was your background in anatomy and physiology before taking this course | |
| Q3. You found the course interesting and capturing your attention | 85% |
| Q4. The lecture materials were useful in understanding selected medical devices | 84% |
| Q5. The device-based tutorials were helpful in facilitating learning of anatomy and physiology by engineering students | 81% |
| Q6. I would have preferred a traditional anatomy and physiology course with no medical device applications | 2% |
| Q7. I feel confident in learning anatomy and physiology on my own after taking this course | 68% |
| Q8. I feel the device-based approach in this course help me understand and retain more knowledge in A&P. | 77% |
| Q9. Rate the importance of different parts of this course. | |

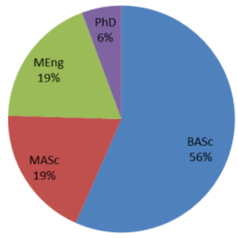


Fig. 3. Degree distribution of respondents .

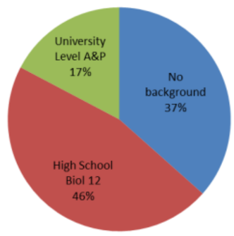


Fig. 4. Prior life-science knowledge of respondents.

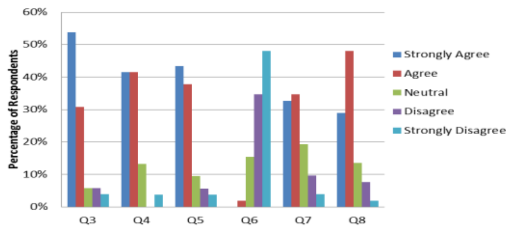


Fig. 5. Graduate responses to Questions 3 to 8.

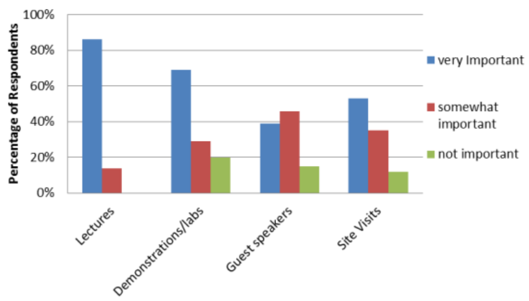


Fig. 6. Graduate responses to Questions 9.

## IV. CONCLUSION

A Biomedical Engineering program should include a balance of curriculum in engineering, industry standards, and life science. The device-based approach of delivering anatomy and physiology has proven to be beneficial in student learning and should be considered as a practical alternative to other traditional approaches.

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