Preparing Biomedical Engineers for Real-World Problem-Solving

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I. Introduction

Over two-thirds of graduating engineers pursue industrial positions immediately following completion of their bachelor’s degree. Upon entering the workforce, the rookie engineer is immediately confronted with challenges like circuit board fabrication, software validation, design reviews, functional requirements, specifications, project scheduling, project management, FDA compliance, 510K’s, clinical trials, ethical debate, patient risk, intellectual property, documentation, and a variety of other responsibilities. Having spent four or more years studying the theory of p-n doping, free-body diagrams, Laplace transforms, Fourier transforms, Kreb’s cycle and Poiseuille’s law, it is no wonder that the recent graduate is frustrated by the seemingly disconnect between higher education and the “real-world”.

Academicians struggle to establish that balance between theory and practice. Many fear that too much “real-world” is simply job training. Yet, too little practical experience leaves the graduate with naive problem solving skills and no appreciation for approximation, optimization and error. Even everyday tasks calibrating a transducer, selecting the appropriate sampling frequency for collecting data from an instrument or writing an effective memo may be beyond the experience of the biomedical engineer trained with classic science and math courses and theory-laden textbooks written for disciplines outside biomedical engineering.

Given the wide spectrum of courses addressing these real-world needs, one might consider where courses fall on a ”reality” scale. At the lowest level of the reality scale are courses using analytical tools like MATLAB, SolidWorks, Mathematica or SIMULINK. Level two requires students working in teams to solve problems with a ”correct answer” (like a physics or chemistry lab). Level three courses might require problems which are structured and researched by faculty, but that could have multiple solutions. As one ascends the reality scale, one finds industrial clients with fuzzy problem descriptions that require initial research to
develop specifications before solutions are generated. At the top of the reality chart would be courses which address the myriad of stakeholders one finds in industry, such as the FDA, U/L, end-users, manufacturing, service, financial, legal, etc.

Real-world experience and exposure can be achieved through a number of mechanisms including design courses, computer simulation, laboratory experiments, guest speakers, industrial sponsorship of design projects, field trips to hospitals and medical industry, internships and cooperative education. In this paper, we describe the mechanisms currently being used in biomedical engineering curricula to create real-world experience and suggest future directions for incorporating the real-world into undergraduate curricula.

II. Real World Skills

When incorporating real-world problems and tasks into the curriculum, one must first ask what skills students need to acquire to facilitate transition into the real world. One goal stated by the BME program at Boston University\(^1\) and echoed by other BME programs across the country, “…[is to provide] students with the skills necessary to solve problems that impact a wide range of economic, environmental, ethical, legal, and social issues.” The minimum skill set required to meet such a goal consists of:

- Critical thinking
- Team work
- Interpersonal skills
- Group decision-making
- Analytic and Problem-solving mechanisms
- Oral and written communication (including selling ideas, and formulating and presenting an argument).

In addition to providing courses specifically targeted for design, biomedical engineering programs should strive to offer real-world experience throughout the curriculum to enhance the skill set previously described.

III. Real-world Experience Throughout the Curriculum

From freshman design to senior capstone design, there are a myriad of real-world experiences being integrated into biomedical engineering curricula throughout the country. Rather than focus on specific design courses, this paper summarizes the real world woven throughout the four-year curriculum.

III.a Laboratory Courses

\(^1\) bme.bu.edu
Laboratory course are used throughout the curriculum to give students hands-on, practical experience in basic science, computing and engineering methods. Students may simply build circuits or mechanical oscillators to study principles of physics or learn to use instruments for biological measurement. In more advanced labs, students typically perform experiments based on clinical and research problems with open-ended solutions. In some cases, students have lab-practicum exams to demonstrate proficiency with practical skills. Most biomedical engineering curriculum offer courses in biomedical instrumentation design with a significant laboratory component. This laboratory provides students the opportunity to prototype circuits, compare theoretical performance to actual performance, use diagnostic instruments (oscilloscopes, spectrum analyzers, function generators), build transducers and collect physiologic data for further analysis. In addition, students experimentally determine transfer functions and other system performance parameters.

Through laboratory investigation students learn to:
- Measure and digitally acquire physical phenomena relevant to medicine and biology
- Design experiments.
- Interpret and statistically evaluate data.
- Write technical reports.
- Compare experimental results with literature and theoretical values and determine quantitatively how protocols, conditions, and methodology may differ and produce observed differences.

To assist in the measurement and analysis stages, a number of institutions use the Biopac Student Lab Advanced System with PC laptop computers to collect and analyze measurements of biosignals from respiratory, cardiovascular, skeletal, muscular, and other systems.

Laboratory experiences may include multi-week group projects where each group is assigned a specific project description and list of objectives. The group must research the literature, and then use the instruments and equipment available in the lab to prepare a protocol, methodology, and data analysis proposal. The proposal may even be presented and defended orally.

III.b Computer Simulation

The simplest demonstration of theory put into practice is through modeling and computer simulation. Simulation of physical and physiological systems may be performed using a variety of software packages such as SIMULINK, Working Model, SIMM, LabView, Mathematica and MATLAB. These software packages are relatively simple to use, require minimal programming skill and allow fairly sophisticated analysis of complex systems. In most applications, students construct models of biomedical systems and compare theoretical performance to experimental data. For example, at Johns Hopkins University\(^2\), freshman BME students begin their studies with a course called, ‘Models for Life,’ where students learn how to model biological systems in a small group tutorial environment. The course emphasizes the modeling aspects of biomedical engineering, integrating the laws of physics and chemistry with mathematics to model biologic phenomena. These modeling experiences give freshman an immediate appreciation for the role

\(^2\) www.bme.jhu.edu
of basic science, mathematics and computing, courses that overwhelm the first years of engineering study.

For the more advanced student, Hopkins’ offers, “High Performance Computing in Biology.” This course combines numerical methods and parallel computing with a broad range of large-scale biological models that consist of coupled reaction-diffusion equations. Students are expected to write an NIH formatted proposal describing the problem and how it will be solved and then implement a solution to the problem.

III.c Internships and Cooperative Education

Several programs offer formalized cooperative education and internship programs to their undergraduate and even graduate BME students. These programs allow students to spend one or more semesters working in industry. These internship experiences give the student a wealth of experience that helps them to define their strengths, weaknesses, likes and dislikes. The experience supplements classroom learning and gives students a purpose to what they are studying.

A number of universities also offer summer research experiences for undergraduates. Most of these summer programs are funded by NSF or the Howard Hughes Institute. Some programs have considered making industrial experience a requirement for all graduates.

The BME program at University of Pennsylvania3 offers “Preceptorship in Clinical Bioengineering.” This course provides lectures and in-depth exposure to a selected clinical program in the School of Medicine. Half the course time is spent participating in programs with clinical faculty, interns, residents and researchers of a selected clinical department emphasizing areas of particular interest and applications to BME. Such a program gives engineers that clinical experience that is lacking in the industrial setting.

Most BME programs offer little instruction in business, despite the fact that many engineers ultimately assume positions in project management and business administration. The University of Pennsylvania offers a course called “Biomed/Biotech in the Marketplace”. Perhaps more BME curricula should allow for business education, particularly in the area of healthcare. The Healthcare Technology Management Program4, a joint Master’s degree program between Marquette University and the Medical College of Wisconsin, is designed to bridge the gap between business and engineering.

III.d Guest Speakers and multiple instructors

Typically, a course is taught by one instructor, and that instructor is expected to teach a fairly broad range of topics, particularly at the undergraduate level. Often, the instructor may have great command of the theory but limited practical experience. Or, the instructor may have

3 www.seas.upenn.edu/be/index.html
4 www.eng.mu.edu/departments/bien

experience with only a fraction of the topics covered in a course. Guest speakers are an excellent means for introducing expertise into a course that is not readily available in the course instructor. When faculty bring in guest speakers or outside experts, they demonstrate to students the need for a team of experts in solving biomedical problems. Students also learn how to probe or question a person to determine the extent of that individual’s expertise and their potential contribution to the team. Furthermore, a combination of speakers from industry, academia, and medicine give students a broad perspective on career options.

Going a step beyond the guest speaker is the use of multiple instructors in a course. While administratively more difficult to organize and implement than a single instructor course, the multiple instructor course takes advantage of multiple areas of expertise. This model has long been used in medical school instruction.

**III.e Research**

As teacher-scholars, professors should make an effort to bring their research problems, data and problem-solving approach into the classroom. Professors may incorporate actual data into homework and computer projects or have senior design teams build instrumentation for the laboratory. Moreover, most BME programs offer one-on-one independent study allowing undergraduate students to perform research on cutting-edge topics using state-of-the-art facilities and techniques. This is an excellent opportunity for students considering research careers to experience the research process.

“Research and Professional Practice I and II” at Tulane University\(^5\) introduces the tools, techniques, and rules necessary to function professionally as a researcher or engineer. Topics include economic analysis, ethics, professional communication including writing and oral presentation, and research techniques including literature search, citation, and the structure of a scientific paper.

**III.f Field Trips (clinical environment and industry):**

One of the complaints that the medical device industry communicates to academia is the lack of appreciation that engineers have for the clinical environment, clinical needs and world health issues. Too many engineers are sitting at a bench or in a cubicle designing for an environment to which they have never had exposure. Some courses address this problem by providing students with multiple tours of clinical facilities. Section III.c also describes how clinical instruction may be incorporated into the curriculum.

**III.g Bioethics instruction**

Recently, accrediting bodies have emphasized the need to better educate students in ethics. Such instruction is important for the biomedical engineer who is developing technology to interface with the human body and potentially alter or prolong life. At a minimum, ethical conduct should

\(^5\) [www.bmen.tulane.edu](http://www.bmen.tulane.edu)
be evaluated in course work and incorporated into the student’s grade. For example, a student writing computer algorithms for class has a bug that occasionally causes the algorithm to produce incorrect answers. One might grade the student in how the situation was handled. Did the student leave the bug and simply turn in the correct computer output for those cases where execution was correct? Did the student make an effort to fix the bug, even at the expense of a late report? Did the student copy another student’s properly functioning code? This type of evaluation prepares students for real world, where the engineer is sometimes confronted with placing faulty circuit boards or software algorithms into diagnostic devices for the sake of meeting a production deadline.

Students should have some appreciation for the human condition and the difficult ethical questions that often arise when new technology is developed. Ethical training may include students securing Human Subjects approval for design projects, formal ethics courses, and regular guest lecturers to address bioethics and case studies.

III. h Problem-centered instruction

Recent findings from the BME Education Engineering Resource Center lead by Vanderbilt University in conjunction with Northwestern University, Texas and Harvard-MIT (VaNTH)\textsuperscript{6,7} suggest that students learn better when topics are presented in a problem-focused, modular format. Perhaps BME curricula should consider abandoning the traditional courses of chemistry, physics, biology and calculus. Instead, TEAMS OF SCIENTISTS, MATHEMATICIANS, PHYSICIANS AND ENGINEERS will TEACH the material in combined fashion using A MODULAR, PROBLEM-FOCUSED approach. In other words, class materials will be presented in a case-study/problem solving approach. Each topic is first introduced within the context of and appropriate biomedical problem. Then, the potential solutions are covered using knowledge of physics, biology, chemistry and engineering methods.

Modular instruction allows for case study/problem-based instruction for modeling and design. It also allows for multiple experts to present course material. Students are forced to combine theory and practice across several disciplines, which is what the graduating engineer will face upon entering the real world, whether it be an industrial, clinical or research environment.

Marquette University’s freshman sequence in Biomedical Engineering Methods I & II is a fully modular, team-taught course whereby each 3-4 week module addresses a biomedical problem or challenge such as physiologic monitoring, medical telemetry, biomechanical modeling, image analysis, and biofluid mechanics. Each module requires 6 hours of laboratory giving students hands-on experience with circuit design, mechanical models, data acquisition, statistical analysis, CAD, technical writing, measurement and team work.


\textsuperscript{7} www.vanth.org
Olin College, which opens its doors next year, will be experimenting with this new model of undergraduate education. Their curriculum will emphasize teamwork, project-based learning and entrepreneurial thinking.  

VI. Conclusion

Mechanisms for preparing biomedical engineering students for real-world problem solving are numerous. Failure to incorporate such real-world experiences throughout the curriculum creates frustration for the student, particularly for the freshman or sophomore undergraduate who lacks the experience to draw a connection between theory and practice. Upon graduation, the biomedical engineer is suddenly confronted with real-world problems and design that require a team of experts, project planning and execution, regulatory and quality control, financial support and a satisfied customer. Too often, graduates are unprepared for this transition to real world engineering.

In designing a curriculum to prepare students for future challenges, we continually ask, “What is the “best practice?” A good design engineer would ask, “how do we measure success?” Do we use metrics like starting salaries? Employer rankings of alums? Alumni surveys? Rankings of US News and World Report? Licensing exams? This is a difficult question to address, and only recently have engineering programs been asked to formally assess the outcomes of their educational process. Many biomedical engineering programs continually assess and remold their curricula to enhance their educational missions in specific, practical, measurable ways, with the goals of improving the effectiveness of training and education. However, these assessments have typically been somewhat informal and randomly distributed. Even with NSF’s solid commitment to engineering design project experiences, and widespread enthusiasm about this experiential approach to learning and service, there is a lack of documented solid empirical support for the efficacy and validity of design project experiences and the specific aspects of implementing those experiences.

If biomedical engineering programs are to prepare students to solve biomedical problems that impact a wide range of economic, environmental, ethical, legal, and social issues, students must be taught how to put theory into practice and how to adapt when real-world behavior cannot be adequately described by existing theory. Every educational tool, from textbooks, to lab experiments, to homework to capstone design projects should seek to incorporate some aspect of real-world implementation and problem solving.

Biography

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Received the B.S.E. from Marquette University and the M.S. and Ph.D. from Northwestern University in 1985, 1987 and 1989, respectively, all in Biomedical Engineering. She is an associate professor of biomedical engineering at Marquette University, and is a past recipient of the University's Robert and Mary Gettel Faculty Award for Teaching Excellence. She currently

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