Work in Progress: A Vertically-Integrated, Project-Focused Approach to Undergraduate Bio-medical Engineering Education

Dr. Amber L Doiron, University of Vermont

Amber Doiron is an Assistant Professor in the Department of Electrical and Biomedical Engineering at the University of Vermont with a research focus on nanoparticles for drug delivery and imaging. Previously she was an Assistant Professor in Biomedical Engineering at Binghamton University. She received her B.S. in Chemistry from Colorado State University in 2003, and she was an NSF-IGERT fellow while earning an M.S. and Ph.D. in Biomedical Engineering from the University of Texas at Austin. She was the T. Chen Fong Postdoctoral Fellow in Medical Imaging in the Departments of Radiology and Chemical Engineering at the University of Calgary. Dr. Doiron also served as the chief scientific officer at NanoPulse Biosciences LLC for four years.

Dr. Jason H.T. Bates, University of Vermont

Dr. Jason H.T. Bates is a professor in the Department of Medicine in the Larner College of Medicine, University of Vermont. His research interests focus on respiratory biomechanics and the pathophysiology of lung disease.

Prof. Ryan S McGinnis, University of Vermont
Dr. Juan Jose Uriarte, The University of Vermont
Niccolo M Fiorentino, University of Vermont
Dr. Jeff Frolik, University of Vermont
Prof. Rachael A Oldinski

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Introduction

The Biomedical Engineering (BME) program at the University of Vermont (UVM) is currently restructuring its required curriculum into a vertically-integrated, interdisciplinary core focused on engineering design and active learning instructional methods in order to prepare our students for dynamic engineering careers in the modern era. Engineering solutions to current and future grand challenges are increasingly interdisciplinary, which is especially true in the field of BME where advancements are often made at the interface of materials, electrical, mechanical, and medical knowledge. Moreover, today's biomedical engineers must be capable problem-solvers who are comfortable working in multidisciplinary teams within the design process. Traditional educational approaches, which leverage standard lecture-style dissemination of siloed information with limited hands-on project and design experience, are not sufficiently preparing our graduates for success in the interdisciplinary, project-focused world [1]. At UVM, foundational technical content is currently taught across the departments of Mechanical Engineering, Civil Engineering, and Electrical Engineering. In the new curriculum, these topics will be integrated into core courses taught in the BME program that cover the critical engineering concepts with direct application to biomedical problems. These core courses will be taught by BME faculty who have the training to work across the boundaries of traditional approaches in order to promote the systems-thinking skills necessary for engineers. Importantly, vertically-integrated engineering design will be included in each year of the undergraduate curriculum in order to increase hands-on experience, creative thinking, and program cohesiveness. All core BME course offerings will be project- and laboratory-based, with an emphasis on active learning and interdisciplinary perspectives on biomedical technologies.

Background

Active learning is increasingly accepted as a superior method for disseminating knowledge, based on the foundation that learning is promoted by instructional methods fostering active student engagement as opposed to traditional lecture-style methods that require students to be passive observers [1]–[3], and many well-regarded BME programs such as those at Worcester Polytechnic Institute, Duke, and University of California at San Diego implement active learning classes. The benefits of active learning include increased engagement, improved learning, and improved performance on formative assessments [3]. Of particular interest to engineering, active learning can be created to encourage students to devise, design, analyze, synthesize, and evaluate their work. These skills fall into the higher order levels in Bloom's taxonomy and are critical in engineering careers. In addition to creating classes that focus on active learning, the new BME curriculum emphasizes interdisciplinary content and projects. BME involves the application of life and physical sciences to engineering problems with medical relevance. Traditional approaches to BME curricula rely on students taking foundational engineering courses in their departments of origin; for example, circuits is taught by the Electrical Engineering department, materials by Mechanical Engineering, and statics by Civil Engineering. Oftentimes, these courses often do not present biomedical examples or content. Applying engineering methods directly to biomedical problems not only serves to pique student interest but also combats siloed views of knowledge that arise in traditional engineering departments. For example, a drug delivery problem may highlight topics typically taught in disparate classes such as materials science, cell biology, physiology, and transport. Focusing on BME problems allows fundamentals that span disciplines to be taught in an active classroom environment, which is an effective way to provide engineering students with a holistic view of the field [4]. Finally, a key limitation of our current curriculum is that it includes engineering design only in Years 1 and 4, with Years 2 and 3 being devoid of formal design experiences within the classroom. In the new curriculum (Figure 1), dedicated courses throughout each of the four years will emphasize the design process and hands-on, experiential learning that can be transitioned into the job market as the students begin careers in industry, research, or a related field. Our new approach to teaching engineering design will involve cross-year student interactions, similar to the multi-university Vertically Integrated Projects (VIP) program led by Georgia Tech.

Implementation

Beginning in the fall of 2020 at UVM, engineering concepts will be taught in three core BME courses of six credits each, scheduled across two consecutive teaching blocks to facilitate lab, project, and active learning strategies. Four BME design courses will be taken before the students culminate their educational experience with the BME capstone design course. BME Core 1 will comprise biomechanics, instrumentation, and sensors; BME Core 2 will comprise biophysics, biomaterials, and transport; and BME Core 3 will comprise modeling biological systems and signals. BME Design course 0 will provide the fundamentals of the design process and engage students with small team-based design projects motivated by the clinical needs of colleagues in our adjacent medical school. Design courses 1 and 2 will cover regulatory standards and validation testing, respectively. BME Design 3 will consist of small-scale, team-based collaborations to aid in the transition into Capstone Design, which is required during the 4th year. An elective second capstone semester will focus on commercialization of technologies.

Our vertically-integrated design sequence will encourage cross-year student interactions. Case studies from capstone classes will be used in Design courses 1 and 2 in the sophomore year. Furthermore, first and second year students will shadow more senior design students for two weeks during design activities and act as a key focus group for design vetting and testing. During junior year, students in BME Design 3 will work in small teams to collaborate directly with capstone teams on small aspects of the project. This will provide the juniors with valuable experience as they transition onto their own required capstone projects in the senior year. Seniors will have the opportunity to identify appropriate design activities to conduct in sophomore classes and mentor sophomore design teams. Cross-year interactions between students will further serve to increase non-siloed, integrated learning across topic areas. Design projects will bridge the assets in the colleges of engineering, medicine, and nursing as experiential learning that is directly applicable to engineering career paths. We envision this approach fostering soft skills such as technical writing, oral communication, and creativity.

New: 39 BME cr. Old : 14 BME cr.	Fall	Spring
Year 1		BME Design 0 (2 cr.) BME 001 Intro to Design (2 cr.)
Year 2	BME Core 1 (6 cr.) BME Design 1 (1 cr.)	BME Core 2 (6 cr.) BME Design 2 (1 cr.) BME Lab I (2 cr.)
Year 3	BME Core 3 (6 cr.) BME Workshop (1 cr.)	BME Design 3 (2 cr.) BME Elective (3 cr.) BME Workshop (1 cr.)
Year 4	BME Capstone Design 1 (3 cr.) BME Elective (3 cr.) BME Capstone Design I (3 cr.) BME Lab II (2 cr.)	BME Capstone Design 2 (3 cr.) BME Elective (3 cr.) BME Capstone Design II (3 cr.)

Figure 1. Before (red) and after (blue) curricula showing an increase in BME-specific credits (39 vs. 14 credits), design courses in all years, and core content taught within BME.

We plan to employ active learning within the BME core classes in the form of hands-on demonstrations, flipped content, laboratory exercises, computer simulations, case studies, and project-based learning. We are currently exploring joining the CDIO Initiative, a system for educating engineers by focusing on conceiving, designing, implementing and operating real-world scenarios. We hypothesize that students who explore biomedical phenomena in a hands-on manner will be more likely to understand those concepts and remain engaged in their course of study. Experiential and active learning materials are being developed by the BME faculty with an eye towards heavily involving colleagues in other colleges, particularly the College of Medicine, which has recently transitioned to a curriculum based exclusively on active learning.

Finally, we aim to promote interdisciplinary interaction in an elective second capstone semester that will focus on commercialization of BME technologies. Coordination with the School of Business will promote learning of technology transfer concepts critical to student transition to industry. We are developing infrastructure to support a Center for Biomedical Innovation (CBI), which will include resources for use throughout the design sequence and will promote the development of data-driven biomedical devices and software that address challenges in rural medicine. The CBI will house the vertically-integrated design sequence in the training of future inventors, innovators, entrepreneurs, and business leaders.

Assessment

Early feedback from current students is positive, with one noting that "integrating the design process into all four years of education will help to engrain realistic practices and prepare students for what we will be doing when we graduate; I wish I could go back and do it again!". Data collection and assessment will be rigorously employed during implementation of this new program, specifically designed for each individual course as well as the overall curriculum. The objectives of these studies will be to test the hypotheses that introducing active learning, BME-focused interdisciplinary course content, and design across four years will elicit improved outcomes related to 1) understanding of engineering concepts, 2) self-efficacy, and 3) student retention. Conceptual engineering knowledge will be quantitatively assessed within each course by comparing answers to concept-matched questions pre- and post-implementation on homework, quizzes, exams, and projects. Self-efficacy, the belief in one's capabilities, will be assessed in student surveys before and after courses and for the curriculum in surveys and reflective student writing at the end of each academic year. Student retention will a means of assessing the student choice to leave or continue in the field. Opinions from faculty, teaching assistants, and the board of directors will be solicited in the form of surveys and interviews.

References

[1] M. Stains *et al.*, "Anatomy of STEM teaching in North American universities," *Science*, vol. 359, no. 6383, pp. 1468–1470, Mar. 2018, doi: 10.1126/science.aap8892.
[2] M. Prince, "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education*, vol. 93, no. 3, pp. 223–231, 2004, doi: 10.1002/j.2168-9830.2004.tb00809.x.
[3] S. Freeman *et al.*, "Active learning increases student performance in science, engineering, and mathematics," *Proc. Natl. Acad. Sci. U.S.A.*, vol. 111, no. 23, pp. 8410–8415, Jun. 2014, doi: 10.1073/pnas.1319030111.
[4] L. J. Everett, P. K. Imbrie, and J. Morgan, "Integrated Curricula: Purpose and Design," *Journal of Engineering Education*, vol. 89, no. 2, pp. 167–175, 2000, doi: 10.1002/j.2168-9830.2000.tb00511.x.