Development of a Novel Foundation Course for Biomedical Engineering Curriculum

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Abstract

The Bioengineering undergraduate program at Rice University is developing novel courses to meet its primary program objectives. Students are required to take seven core Bioengineering courses and five elective courses in one of the three tracks of Cellular and Molecular Engineering, Systems Engineering and Biomedical Instrumentation, or Biomaterials and Biomechanics. The authors have developed a new sophomore-level course, Conservation Principles in Biology and Medicine, that lays the foundation for achieving the program objectives, prepares students for upper-level core courses, and exposes students to material in all three tracks. This course introduces the general conservation law and then focuses on the application of conservation of mass, momentum, charge and energy in biological systems. Course examples span the breath of modern bioengineering: physiology, biochemistry, tissue engineering, kinematics, biomaterials, biotechnology, cellular engineering, and instrumentation. One unique feature is the use of case studies at the end of the course to illustrate the concept that various conservation principles can be applied to understand and to model different aspects of a system. Case studies of the kidney, cellular metabolism and the circulatory system have been developed. Finally, a group term project focused on modeling an organ and describing an assist device synthesizes material. The term project also emphasizes team work and written and oral presentation skills which are taught in conjunction with the Cain Project in Engineering and Professional Communication. Assessment includes extensive mid-year and terminal surveys which focus on content, mode of presentation and quality of teaching. Conservation Principles in Biology and Medicine is serving as the template for incorporating ABET 2000 into a new department. Course notes are being developed into a textbook for biomedical engineering students.

Biomedical Engineering Curriculum at Rice University

The Bioengineering undergraduate program at Rice University is designed to prepare students for careers in the rapidly developing areas of biomedical engineering and bioprocessing. The undergraduate educational program in Bioengineering has the goal of producing a new type of biomedical engineer, fully conversant with modern biochemistry and cell and molecular biology. This type of biomedical engineer translates bench-scale scientific advances in biological sciences into cost-effective new products and processes. New and innovative curricula are being developed to educate biomedical engineers who not only create new tissues and cell-based therapies but also deliver them at a cost affordable to our health care system.

The educational program objectives of the B.S. degree in Bioengineering are to:

- Provide students with a fundamental understanding of mathematics, engineering and science, including the life and medical sciences
- Teach students to apply engineering principles in the life and medical sciences
- Develop their critical problem solving skills in bioengineering
- Develop their ability to communicate effectively and participate in interdisciplinary teams
- Expose students to a broad education that prepares them for diverse careers.

Graduates will be prepared to pursue further education in graduate school or medical school or begin a career in the biotechnology industry.

Bioengineering students follow the typical engineering curriculum during their freshman year with two semesters of calculus, two semesters of general chemistry, an introductory programming course and two semesters of physics. The introduction of the students to the fundamentals of life sciences begins with two semesters of organic chemistry and introductory biology in the sophomore year. Biochemistry and cell biology are critical for our program and are taken in the junior year. Because of the increasing importance of computer-based solutions in bioengineering, students take two more semesters of mathematics and one semester of engineering computational methods, which covers a rigorous introduction to analytical and numerical methods.

Students obtaining a B.S. in Bioengineering are required to take seven core courses in Bioengineering. The core courses include the following (1 semester each):

- Conservation Principles in Biology and Medicine - conservation of mass, momentum, charge and energy in biological systems
- Biosystems Transport and Reaction Processes - momentum, heat and mass transport and reaction processes in the human body
- Systems Physiology - physiology at the organism, tissue and cellular levels
- Biomechanics and Biomaterials - force analysis, mechanics of deformation, biomechanics of tissue, physical and chemical properties of biomaterials
- Tissue Culture Laboratory - sterile technique; cell proliferation and transfection assays
- Bioengineering Design - design of process or product, FDA regulations, economics
- Advanced Bioengineering Laboratory - laboratory modules in biomaterials, biomechanics, systems physiology, instrumentation, bioprocessing and ethics.

To enhance knowledge in one area of Bioengineering, students select one of three emphasis areas or tracks: (a) Cellular and Molecular Engineering, (b) Systems Engineering and Biomedical Instrumentation, or (c) Biomaterials and Biomechanics. Students take a minimum of five elective courses that expose them to important problems in their chosen track. Examples of courses in the Cellular and Molecular Engineering track are Cellular Engineering, Tissue Engineering, Biotechnological Processes and Gene Therapy. Examples of courses in the Systems Engineering and Biomedical Instrumentation track are Medical Imaging, Biophotonics Instrumentation and Neurobiology. Examples of courses in the Biomaterials and Biomechanics track are Biomechanics of Human Movement, Tissue Engineering, Biomaterials Engineering and Mechanics of Deformable Solids.

Novel Foundation Course: Conservation Principles in Biology and Medicine

The course, Conservation Principles in Biology and Medicine (BIOE 252), covers the fundamental conservation laws with applications in the biological and medical sciences. The course is taught to sophomores and is the first in a series of Bioengineering courses designed to equip students with solid engineering and problem solving skills and to expose them to interesting and exciting applications in the life and medical sciences. Prerequisites for students include two semesters of college-level calculus, general chemistry, biology and some rudimentary computational skills such as Matlab.

Formulations of the conservation laws for mass, momentum, charge and energy are explored in a range of biomedical systems. A deliberate effort is made to include example and homework problems that cover from the cellular level to the whole organ systems level and span the breath of modern bioengineering: physiology, biochemistry, tissue engineering, kinematics, biomaterials, biotechnology, cellular engineering, instrumentation, etc. The engineering principles, problem solving approach and technical rigor make this a good foundation for further engineering courses in transport, biomechanics, biotechnological processes, instrumentation, systems physiology and other courses.

Applications of conservation laws form the first semester foundation courses in many engineering curricula. Conservation of mass and energy is typically the first course in a chemical engineering curriculum. Conservation of momentum including statics and fluids is often the foundation course in mechanical engineering. Finally, conservation of charge forms the groundwork for an introduction to electrical circuits. The authors believe that covering the conservation laws with applications in biological systems should serve as the foundation bioengineering or biomedical engineering course. Depending on a department's particular curricular needs, an instructor can select and emphasize particular conserved properties. In the Bioengineering program at Rice University, mass, energy and momentum are emphasized. In a department where instrumentation is the focus, conservation of charge and energy may be emphasized.

The course begins with a basic review of engineering calculations. Unit conversion and dimensional homogeneity are reviewed. The physical variables commonly encountered in engineering are elaborated. For example, mass and mole fraction, force, momentum, flow rates and different forms of energy are highlighted. A methodology or process for solving engineering problems is introduced and is used throughout the course. Issues such as significant figures and presentation and analysis of data are discussed. While this material may be review for many students, we choose to reinforce it since it is the first in a sequence of Bioengineering courses.

The second topic in the course is presenting the governing accounting and conservation laws. The governing accounting law is generalized as follows:

In - Out + Generation - Consumption = Accumulation.

where the terms represent the movement in and out of and/or reaction of an extensive property in a system. Both the accounting and conservation equations are given in algebraic, differential and integral forms. Definitions of open, closed, reacting, non-reacting, steady-state and dynamic systems are explored. Examples are given to illustrate these concepts.

The rest of the course is split into the four sections of conservation of mass, momentum, charge and energy. For each property, basic concepts are reviewed and the accounting and conservation laws are explicitly formulated. We reinforce that the conservation laws are parallel across the four properties.

Conservation of mass is covered first since it is the most concrete of the conserved properties. Open systems with multiple inlets and outlets, multiple components and/or multiple units are discussed. Rigorous treatments of chemical and/or biological reactions are given. Dynamic systems are also discussed. Example problems include mixing in the stomach, an artificial liver device, drug delivery and the culture of plant roots.

Conservation of linear momentum is introduced next and is linked to Newton’s Laws of Motion. Rigid bodies and fluid are discussed in steady-state and dynamic systems. Formulations of the Reynolds number and the Bernoulli equation are given. Conservation of angular momentum is briefly reviewed. Example problems include loading of a bone, hematocrit concentration in a flowing vessel, flagella movement and flow in a stenotic vessel.

The basic concepts of net and total charge introduce the conservation of charge section. Conservation of charge in open, steady-state systems is linked to Kirchhoff’s Current Law. Dynamic and reacting systems are also discussed. Example problems include radioactive decay, charging of a capacitor and pH control in a bioreactor.

The section on conservation of energy beings with types of energy and state and path functions. Steady-state enthalpy balances such as change in temperature and phase are presented. Systems with chemical and/or biological reactions as well as dynamic systems are discussed. Example problems include heat of reaction during glucose respiration, warming of the bloodstream and heat loss during respiration.

One unique feature of this course is the presentation of case studies which are designed to bridge across the different conservation applications of mass, momentum, charge and energy. Case studies of the circulatory system, cellular metabolism and the kidneys have been created. We explicitly choose case studies focused at both the cellular and tissue levels. For each case study, biological and/or medical background is discussed. Then, the conservation law is applied to answer different questions about the system. For example, the following are a subset of problems for the case study on the kidney:

- Mass flow rates and concentration of urea, creatinine, uric acid, and water
- Recovery of charged ions
- Interrelationship of renin secretion, blood pressure and blood flow

- Energy use of dialysis machine.

Usually three lectures are devoted to one case study at the conclusion of the semester. The case studies effectively synthesize and reinforce material from throughout the semester and provide more complete “real-world” examples of engineering in biology and medicine.

Another unique feature of this course is termed the interviewing project. The objective of this activity is to expose the students to perspectives on career options and research opportunities in the “real-world.” The class is divided into groups of four to five students. Students take a proactive role in asking questions to or interviewing a business person or researcher about his/her business, job, university experience and other training. Staff from the Cain Project in Engineering and Professional Communication coach the students to assist them with strategies for asking good questions. Each student writes a two-page summary of the interview, and reports are graded on discussing job responsibilities, information obtained about the company or institution, style and grammar. One student from each group presents a five minute report on his/her professional in class so that all students are exposed to the different career opportunities. Participating local companies and institutions include University of Texas Health Science Center, M.D. Anderson Cancer Center, Tanox, Cyberonics, Genometrix, Prucka Engineering - GE Marquette, and Wyle Labs (NASA contractor).

A group term project gives students the opportunity to study a system in depth and work collaboratively in a team. A recent project involved modeling the lungs and heart-lung bypass machine. For example, the following are a subset of the problems posed for the project on the lungs:

- Regions of laminar and turbulent air flow in lungs
- Three compartment model of respiration
- Inhalation of allergen, with and without asthma
- Estimate energy and pumping requirement for heart-lung bypass machine

Students work in teams of three or four. Preliminary project sketches are required. Oral reports are given in class the last week of the semester. One person from each group gives a 12 minute presentation; additional time is allotted to answer questions from the class audience. The final written reports are 10-15 pages and include strategy for completing calculations and models, assumptions, results of calculations and modeling efforts, and implications of calculations. Staff from the Cain Project in Engineering and Professional Communication assist students to improve the effectiveness of their presentations.

Assessment includes extensive mid-year and terminal surveys which focus on content, mode of class presentations, and quality of teaching. Based on evaluations, emphasis on problem solving during class has increased. Course organization has also shifted due to student and instructor feedback. Conservation Principles in Biology and Medicine is serving as the template for incorporating ABET 2000 into a new department.

The website for Conservation Principles in Biology and Medicine course at Rice University is as follows: http://www.owlnet.rice.edu/~bioe252/. Course notes are being developed into a textbook under a contract with Prentice Hall; expected publication date is January 2003.

Biographical Information

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