Design of a two-semester transport sequence for biomedical engineering undergraduates

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Introduction

As a relatively new undergraduate field of study, biomedical engineering curricula vary significantly from university to university. In attempting to train undergraduate students for both industry and academia, the program at Saint Louis University has a combination of traditional basic engineering courses and upper level biomedical engineering specific courses. While the basic courses cover essential engineering topics and attempt to incorporate biomedical examples, the upper level courses specifically target biomedical topics, using the basic engineering principles as a basis. This paper describes the organization and contents of a two-semester transport sequence for undergraduates, covering topics from Navier-Stokes to bioartificial organs.

Design of First Course

The first course was designed as a traditional engineering course in Transport Phenomena, focusing on the fundamental problems, with prerequisites of differential equations and mechanics (syllabus can be found online at www.slu.edu/colleges/parks/departments/BME/curriculum/330/bme_330.html). Topics included mass, energy, and momentum balances, development of Navier-Stokes, convection and conduction, and diffusive mass transfer, using the text by Welty, Wicks, Wilson and Rorrer [1, 2]. These topics were covered using the "horizontal approach"[1] to allow all of the above topics to be introduced in a one semester course. The objectives of the first course were: (i) to prepare the students for more advanced topics in Transport Phenomena by solving problems at the fundamental level, (ii) to relate the topics discussed in class to biomedical problems, and (iii) to improve their written communication skills on topics related to transport.

Although the first objective can be accomplished with the help of the text, few biomedical problems or concepts are available in the current text until the mass transfer section. Therefore, one additional component was added to fulfill the second and third course objectives. The students were each required to find and review a total of three (one per month) scientific journal articles on topics that were covered in class and were related to biomedical engineering. The review consisted of a summary of the article as it relates to transport, including the relevant equations and assumptions, and a critique of the article, including potential problems with the analysis, organization of the writing, and overall significance of the work. The reviews not only gave the students a chance to see 'what's out there,' but also allowed them to work on their written communication skills. Therefore, the papers were graded both on scientific content and grammar.

Design of Second Course

While the first course covers fundamental concepts in transport phenomena, the second course uses those concepts and applies them to biomedical situations such as mass and fluid transfer in the body and in artificial organs (syllabus can be found online at www.slu.edu/colleges/parks/departments/BME/curriculum/430/bme_430.html). The text by Fournier was chosen because it covers more advanced topics assuming basic transport knowledge[3]. Topics include physical properties of the body and cells, solute and oxygen transport in biological systems, transport properties of blood, pharmacokinetic analysis, extracorporeal devices, and bioartificial organs. Throughout the course, it was essential that students recognize the limitations of solving problems with fundamental equations and the importance of assumptions when investigating realistic problems. Therefore, the objectives for this course were: (i) to analyze mass and fluid transport both in the body and in bioartificial organs, (ii) to create, fabricate, and implement a laboratory for introductory transport, and (iii) to improve oral communication skills for scientific presentations.

The text was used in combination with traditional lecture to, in part, accomplish the first objective. Scientific papers from various journals were used to supplement the text and to bring current research into the course (Table 1). Each student was assigned a paper to prepare for oral presentation. The presentations were to include any necessary background, biomedical significance, brief methods and results (including assumptions), conclusions, and a brief critique of the article. Papers were presented after each chapter and students were quizzed on the paper prior to presentation and responsible for the material presented for exams. Each paper typically led to a class discussion about the work and its relevance to other systems.

Table 1: Sample of scientific journals used to emphasize research on topics covered in the textbook for Biotransport

Journal	Research Topic(s)
American Journal of Physiology	fluid transport in lens epithelium [4]. model for glomerular filtration [5]. erythrocyte aggregation [6].
Chemical & Engineering News	drug delivery [7].
Annals of Biomedical Engineering	microvascular blood flow [8]. modeling body dehydration [9]. Fahraeus Effect [10].
Biological & Pharmaceutical Bulletin	topical drug delivery – pharmacokinetic model [11].
Biotechnology Progress	naphthalene toxicity – pharmacokinetic model [12].
ASAIO Journal	intravascular oxygenators [13].
Kidney International	diffusive transport in peritoneal dialysis [14].
Journal of Biomedical Materials Research	encapsulation of cells for insulin control [15, 16].

To accomplish the second objective, a semester long group project was assigned to develop an experiment based on teachings in the first semester. The project constraints were given as follows:

1) topic – the topic must be conceptually related to a biological/biomedical phenomena and should act as a model for that situation
2) resources – the equipment in the student laboratory can be utilized but not permanently removed and any purchase requests must be approved before mid-semester
3) time – each group was required to meet once per week, with all personnel assignments, sketches, ideas and discussions noted in a group notebook; monthly updates were required
4) audience – the audience (college, high school, elementary student) of the experiment must be addressed and be consistent with the final product

Each group had between 3-4 members and each member was assigned a role in the group (leader, secretary, resource person) with the roles were changed monthly. The project allowed students to develop protocols, troubleshoot problems with design and set-up, begin to understand their strengths and weaknesses in a team environment, and conceptualize transport phenomena as applied to biological situations.

Discussion

This sequence has been taught as described three times and two complete sequences of student feedback in the form of course evaluations have been complied. Specific evaluation questions regarding the project will be added this semester (Spring 2002).

The evaluations for the first course typically do not include specific comments on the writing assignments. However, in evaluations for the second course approximately 30% of students (9/31 responses over 2 years) answered the question "What did you like most about this course?" with journal articles, discussions, or primary applications. No negative comments were written regarding the articles. The project has had mixed reviews, being the best (23% 7/31 responses) and the worst (3% 1/29 responses) part of the course. Many students commented on the structure of the project; some of these comments have been incorporated into the project for future years. For example, the comment "for the project, have instructor meet with group more often" has prompted regularly scheduled meetings with each group, along with progress reports, as a means of keeping the project on schedule. Further, students have commented in person that the skills they obtained in completing the project for this course were helpful both in other courses (other faculty have recently added a laboratory design component to their courses) and their senior design project.

The experiments that have been designed have included fluid, heat, and mass transfer examples with the focus of the audience being college-level students (Table 2). The laboratories for high school students have been displayed to students and parents who have visited the department, however, their use has been limited due to technical problems with the labs. Currently, there is no laboratory section for introductory transport because few biomedical transport laboratories exist in practice. However, one of the experiments designed in Biotransport was used in Transport Fundamentals in Fall 2001 as a homework assignment. The laboratory examined heat transfer (Modeling heat transfer in the human capillary) and required both a prelaboratory exercise and a thorough final report. Although there were a few technical problems with the laboratory, student feedback was positive about the experience. When asked “What did you like most about the course?” one student remarked, “I liked the lab… doing the lab help me understand the material.” Another student commented, “more labs could help” when asked “How could the course be improved?”

As the number and quality of the projects increase, more laboratories will be implemented in the first course either as homework assignments or an additional laboratory section.

Table 2: Completed projects from Biotransport.

Title	Audience
Heat transfer through materials used in everyday life	Transport students
Measure temperature from an extended surface	Transport students
Semi-permeable membranes and your body	High School students
Heat loss: staying warm in the outdoors	High School students
The measurement of relative pressure through a flow system using simple manometers	Transport students
The effects of coronary artery disease	Transport students
Modeling heat transfer in the human capillary	Transport students
Simple diffusion lab	Transport students
Conceptual model of nephron function	High School students

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