120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #7035

Work in Progress: Computational Modeling of Biomedical Devices with Active Learning Strategies

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Dr. Tom Merrill's research interests include energy systems, biotransport modeling, and medical devices. Prior to Rowan University, Dr. Merrill worked for thirteen years at a number of places including United Technologies Carrier, Abiomed, Wyeth Research, MicroDose Technologies, and at a medical device start-up company called FocalCool. He received his degrees in Mechanical Engineering from Penn State (Ph.D.), the University of Michigan (M.S.), and Bucknell University (B.S.). He currently teaches thermodynamics, heat transfer, fluid mechanics, and biofluids.

Works in Progress: Computational Modeling of Biomedical Devices with Active Learning Strategies

Abstract

Biomedical engineers need to be able to model transport processes quickly and accurately to produce competitive and safe products. These products include items like drug-eluting stents for coronary artery disease and therapeutic contact lenses for glaucoma. Collaborative learning strategies are used to help students gradually build confidence and skill. Learning goals that include literature reviews, problem formulation, the ability to balance skepticism and creativity, and communicating results are assessed with standard tools: homework, exams, reports, and oral presentations. Student deliverables are used for post-graduation interviews and at a university-sponsored STEM symposium.

Introduction

Today's medical device market is vast. It is also competitive. As a result, there is a need for biomedical engineers to know how to model new designs quickly and effectively. To train future engineers to meet this need, over the last three years we have developed an innovative engineering senior elective and master's level class that combines active learning strategies with today's latest modeling tools.

Course Outline

Instruction has four components: 1) a review of past transport principles (momentum, heat, and mass), 2) a demonstration of the power and effort necessary to solve problems numerically, 3) hands-on activities to learn how to use a commercial finite element package to solve biomedical transport problems, and 4) an overall understanding regarding the practical considerations in a real medical device company. These four distinct areas are not siloed, instead continually woven together.

There were four course learning goals. Students were told that by the end of this course they should be able to:

1. Understand and apply the steps required to attack a biomedical problem: formulation, software implementation, and accuracy checking.
2. Read the literature regarding the biomedical knowledge base and put those ideas to work to solve a problem.
3. Create a healthy balance in your thinking, between creating novel solution ideas and maintaining skepticism about the solutions they provide.
4. You should be able to communicate your approach and findings concisely and clearly, preparing you to play a key role is solving more complex problems that require collaboration after you graduate.

These overarching aims were assessed with homeworks, laboratory reports, a final comprehensive exam, a final report presentation, and final report. In each case rubric was used to quantify performance based on the following general C^4 philosophy inspired by Michael Prince at Bucknell. (C1) Is the work Comprehensive, did it answer all the questions posed or address all the areas of interest? (C2) Is the work Correct? (C3) Is the work clear, can I understand it without struggle? (C4) Is the work concisely shared or is it wordy or bloated in language?

Course Instructor-Led Laboratories

Student teams (two or three students) are asked to tackle a biotransport problem that addresses an important disease or health concern. Recently we focused on glaucoma treatments and understanding burn injury.

The glaucoma laboratory involves modeling the diffusion of therapeutic drug through the eye. Figure 1 shows a schematic of a human eye and a therapeutic contact lens used to carry and deliver drug. This problem is based on a tutorial found in the textbook "An Introduction to Modeling of Transport Processes" by Datta and Rakesh [1].

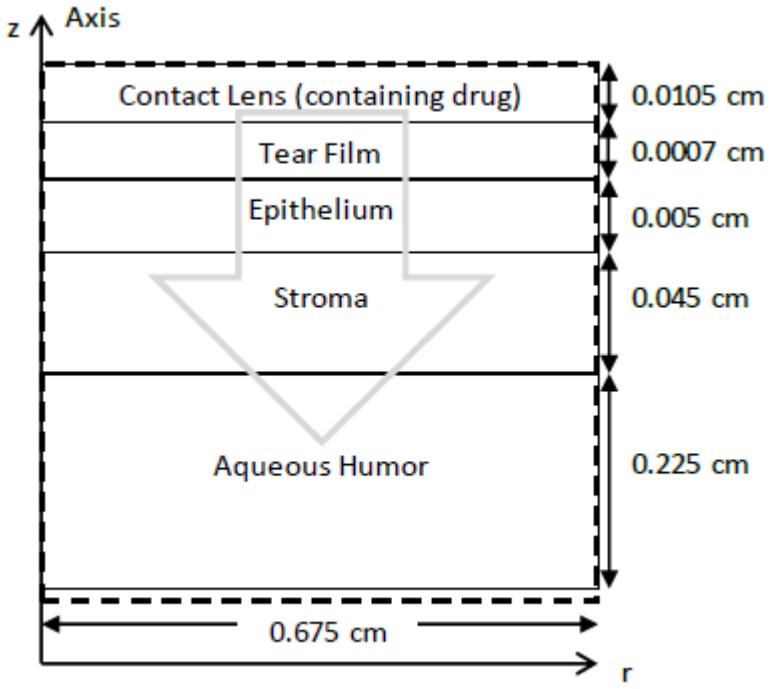

Figure 1: An axisymmetric drawing of the human eye with drug delivery from a therapeutic contact lens (located at top). Students were asked to solve for the drug concentration with time at various points inside the eye.

The laboratory tutorial provides step-by-step guidance involving problem definition, geometry and mesh creation, selection of boundary and initial conditions, fine tuning solver settings, and finally post-processing results. The following laboratory-specific learning objectives were defined for this lab: "At the end of this lab students should be able to:

1. Organize a basic biotransport problem on paper and translate it to be solved in Comsol Multiphysics (CMP)
    a. Open CMP and select the correct application mode
    b. Create a geometry and apply boundary conditions and subdomain values
    c. Create a mesh that leads to a solution
    d. Solve the problem by selecting the correct solver
    e. Perform parametric studies

2. Post process information from the CMP model using surface and integration techniques that include:
    a. mesh quality and surface plots (descretization error)
    b. concentration behavior with time and space
    c. the impact of diffusivity and geometry on final results (sensitivity)

3. Explain mass transfer concepts:
    a. mass and species conservation
    b. mass flux
    c. concentration profiles
    d. species sources and sinks"

Additional questions required students to explore parametric studies to gain an appreciation of what parameters are vital and what are not. To provide opportunities for higher level Bloom's Taxonomy activities, we ask: are there ways to increase drug concentrations at particular time intervals? Is there any concern about residual drug levels at the end of the study duration? Is there a better way of delivering the drug? Are drugs the best approach?

A burn injury laboratory explores thermal transient modeling using a degree of tissue injury model to approximate first, second, and third degree injuries [2]. The context for this laboratory is introduced by asking how are firefighting materials and equipment designed or selected. This laboratory follows the same approach as the previous laboratory: an overall learning objective and an "additional questions" handout is provided followed up with a tutorial for step-by-step guidance. The intent is to provide clear aims for the student as well as structure to help build skills and confidence.

Course Student-Selected Projects

Collaborative learning was fostered by allowing teams of two or three students to take on a self-selected biomedical problem. Entire class periods are dedicated to modeling the problem.

Typical problems included drug eluting stents, hollow fiber membrane dialysis machines, heat loss to the hand under Artic conditions, oxygen transfer in contact lens with increasing protein deposits, and rapid localized brain cooling to help reduce brain tissue damage from ischemic strokes.

With seven or eight different teams working together in one computational lab there is excellent cross-pollination of modeling "tricks". My focus is on student-driven exploration without structure. As each team explores solutions I actively seek ways to facilitate information exchange. For example, if one team successfully completes a contour plot showing the behavior of three variables with clarity, I either directly linkup other teams, make a classroom announcement, or request that the contour plot team post a helpful tutorial on the classroom wiki.

Parametric studies are done to explore design improvement potentials – once again seeking higher level Bloom's Taxonomy activities. Their final reports are designed to approach scientific publication standards, spanning problem formulation to results verification through testing or comparison with published literature. Basic components include an executive summary, an introduction, a mathematical statement, a solution strategy, a results and discussion section, and finally a conclusion.

Common pitfalls include poorly drawn figures that are difficult to understand or incomplete legends, boundary conditions for every boundary are not clearly defined, governing equations are not shown in reduced format to indicate what exactly was solved, and unexpected behaviors arising from parametric studies are not explained.

Conclusion

At the beginning of this class students are told that computer solutions are seductive and often wrong. With time and effort students are able to refine this healthy skepticism while simultaneously building confidence to formulate and solve biotransport problems successfully.

As a result of this class each year we have had increased student activity in a university-wide STEM symposium as well as the annual ASME Summer Bioengineering Conference. We are currently working to integrate this course material into a new NSF TUES grant entitled: Organizing the Curriculum - Enhancing Student Understanding of Core Engineering Concepts through Biomedical Activities (NSF DUE-1140631). We appreciate this NSF support.

References

[1] A. Datta, V. Rakesh, An Introduction To Modeling of Transport Processes, Cambridge University Press, Cambridge, United Kingdom, , 2010, p. 221.

[1] A. Datta, V. Rakesh, An Introduction To Modeling of Transport Processes, Cambridge University Press, Cambridge, United Kingdom, , 2010, p. 243-250.