BEE 4530/MAE 4530. Computer-Aided Engineering: Applications to Biomedical Processes
Spring Semester 2009

Credit: 3 hours

Catalogue description:
Introduction to simulation-based design as an alternative to prototype-based design. Analysis and optimization of complex real-life processes using physics-based computational software. Biomedical applications of heat and mass transfer are covered that includes drug delivery and thermal therapy such as laser heating and cryosurgery. Computational topics introduce the finite-element method, pre- and post-processing, and pitfalls of using computational software. Students choose their own term project, which is the major component of the course (no final exam).

Required or Elective: Elective

Prerequisite(s): Heat and Mass Transfer [BEE 3500 (Biological and Environmental Transport Processes), ChemE 3240 (Heat and Mass Transfer), MAE 3240 (Heat Transfer) or equivalent].

Textbook(s) and/or other required material:

Course objectives:
Upon completion of this course, students should:
1. Be able to identify and formulate engineering problems that involve heat and mass transfer, from the real world into a computer model.
2. Be comfortable in thinking of computer simulation as an important practical tool in design and research projects in industry and academia. Should be able to solve less complex problems on his/her own and can work with a group of experts in solving problems of increasing complexity.
3. Know the essential components of a typical computer prototyping software and has realistic ideas about the advantages and pitfalls of such a software.
4. Be able to integrate engineering analysis with biomedical processes.
5. Learn about several biomedical processes in drug delivery and thermal therapy.

Topics covered:
Introduction to Design and Computer Prototyping
  Problem Formulation
    • Fundamentals of Problem Formulation
    • Governing Equations for Continuity, Flow, Species Mass Balance and Energy
    • Boundary Conditions
    • Material property and Other Input Parameters
    • Source Terms in Heat and Mass Transfer

Numerical Methods
  • Finite Element Method
  • Solving the Linear Set of Equations
  • Linearization of Non-Linear Equations, Solving Multiple Sets of Equations
  • Errors in Numerical Solutions, Convergence
  • Accuracy in Transient Calculations

Software for Fluid Dynamics, Heat Transfer, Mass Transfer and Mechanics
  • Components of a Typical Software Package
  • Computer implementation of problem: COMSOL Software Instruction

Validation, Sensitivity Analysis and Debugging

Class/laboratory schedule, i.e., number of sessions each week and duration of each session:
Two 50-minute lectures and one 50-minute lab each week (averaged over the semester).

Contribution of course to meeting the professional component:
This course partially fulfills the requirement to complete a Field Approved Elective in the Biological Engineering Concentration. For students opting to do a Minor in Biomedical Engineering, the course can be used in one of the categories of the minor program.

**Course outcomes and their relation to ABET program outcomes a-m:**

Upon completion of this course, students should:

1. Be able to formulate a real world engineering problem that involves heat and mass transfer and/or fluid flow in terms of a computer model. Be able to apply this modeling concept to biomedical processes. (a, e, g, k, l-b)
2. Be comfortable in thinking of computer simulation as an important practical tool in biomedical design and research. Should be able to solve less complex problems on his/her own and can work effectively with experts in solving problems of increasing complexity. (a, e, i, k)
3. Know the essentials of computing methodology and their implementations in a typical computer prototyping software. Have realistic ideas about the advantages and pitfalls of such software. (k)
4. Learn about several biomedical processes in the areas of drug delivery and thermal therapy. (a, e, l-b)

**Outcome Assessment:**

In the two written exams, questions test understanding in 1) Ability to formulate a mathematical problem from a biological one; 2) Organization of a typical computer-aided engineering software; and 3) Subject matter (biomedical process modeling, numerical methods). Group projects (worth 45% of course grade) are assessed through formal presentation and a final report.

**Ethical Behavior Statement**

Reference to Cornell University Code of Academic Integrity is made explicitly in the course syllabus and during the first day of classes. Other detail of the academic integrity that is required of the students is also described in the Syllabus that is handed out on the first day.

**Course Webpage**

http://courses.cit.cornell.edu/bee4530/

**Person(s) who prepared this description and date of preparation:**

Ashim Datta, 5/14/09
Course #: BEE 4530  Title: Computer-Aided Engineering of Biomedical Processes
Semester/Year: Spring 2009
Instructor: Ashim K. Datta

Identify the outcomes associated with this course.

Place a “P” or “S” in the left column and leave others blank.

P = Primary outcome that is assessed (suggest 2-3 Primary Outcomes)

S = Secondary outcome that is also assessed

<table>
<thead>
<tr>
<th>P or S</th>
<th>Outcome</th>
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<tbody>
<tr>
<td>P</td>
<td>(a) an ability to apply knowledge of mathematics, science, and engineering</td>
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<td>(b) an ability to design and conduct experiments, as well as to analyze and interpret data</td>
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<td>(c) an ability to design a system, component, or process to meet desired needs</td>
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<td>(d) an ability to function on multi-disciplinary teams</td>
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<td>P</td>
<td>(e) an ability to identify, formulate, and solve engineering problems</td>
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<td>(f) an understanding of professional and ethical responsibility</td>
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<td>S</td>
<td>(g) an ability to communicate effectively</td>
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<td>(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context</td>
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<td>S</td>
<td>(i) a recognition of the need for, and an ability to engage in life-long learning</td>
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<td>(j) a knowledge of contemporary issues</td>
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<td>P</td>
<td>(k) an ability to use the techniques, skills, and modern engineering tools necessary</td>
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<td>P</td>
<td>(l-b) an ability to integrate modern biology with engineering principles</td>
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## (C) COURSE OUTCOMES ASSESSMENT MATRIX

<table>
<thead>
<tr>
<th>Course Outcomes Specific to Course</th>
<th>ABET a-f criteria</th>
<th>How criterion is met</th>
<th>Examples of assessment</th>
<th>Assessment* Level of achievement relative to stated goal</th>
<th>Proposed Action</th>
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<tbody>
<tr>
<td>Be able to formulate a real world engineering problem that involves transport processes, in terms of a computer model. Be able to apply this modeling concept to biomedical processes</td>
<td>Primary (a, e, k, l-b) Secondary (g)</td>
<td>Semester-long student project where each student group selects a biomedical process to be modeled. Project carries 45% of the grade.</td>
<td>Student project reports are available at <a href="http://ecommons.library.cornell.edu/handle/1813/12642/browse-title">http://ecommons.library.cornell.edu/handle/1813/12642/browse-title</a>. Each project is graded for 1) accomplishment of specific steps in modeling (schematic, governing equation, mesh convergence, validation, sensitivity analysis); 2) Quality of written final report; 3) Quality of oral presentations. Problems 1,2,3 in Exam I, dealing with problem formulation. Problems 4-7 in Exam I, dealing with mesh convergence, validation and sensitivity analysis. Five individual problems (see details of the Homework 1-3)</td>
<td>Goal Met: Class mean on the project was 101.8 out of 100 (Bonus points were added to a few projects that clearly did beyond the expected work. Maximum bonus point was 5) Class mean for Exam I was 73.0 out of 96. GOAL: 70%</td>
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<td>Be comfortable in thinking of computer simulation as an important practical tool in biomedical design and research. Should be able to solve less complex problems on his/her own and can work effectively with experts in solving problems of increasing complexity.</td>
<td>Primary (a,e,k) Secondary (i)</td>
<td>Semester-long project Exams I and II, carrying 40% of the total grade</td>
<td>The students are required to relate the computation to design/research practical issues. They also start from a practical issue/problem. Problems 6 and 7 in Exam I dealt with relationship of computing to design. Problems 1-3 in Exam I dealt with relationship of simulation to providing answers for real processes.</td>
<td>Goal Met: Project grade mean for the class was 101.8 out of 100. Mean grades in Exam I and Exam II were 73 out of 96, and 51.8 out of 95, respectively.</td>
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<td>Topic</td>
<td>Primary Category</td>
<td>Description</td>
<td>Goal Met/Partially met</td>
<td>Group Evaluation Aspect</td>
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<td>Know the essentials of computing methodology and their implementations in a typical computer prototyping software. Have realistic ideas about the advantages and pitfalls of such software.</td>
<td>Primary (k)</td>
<td>Semester-long project, carrying 45% of the grade. Completion of four tutorials and associated work that tests the mastery of the computing steps; carries 8% of the grade. Exams I and II, carrying 40% of the grade. Project report is required to show clear understanding of all of the computing methodology used. The group members evaluated each other three times during the semester, using a computer-based group evaluation system. This made sure that everyone in a group of 4 is contributing to the project about equally. Four tutorials (Case Studies I and II; Case Studies VII and IX) to be submitted by individual students (not as a group). Problems 1-8 in Exam II dealt with the fundamentals on which the simulation is based (e.g., governing equations, source terms from electromagnetic heating, finite element method), such that the student is not thinking of the process as blackbox; this would make them comfortable in extending to more complex problems.</td>
<td>Goal Partially met: Class mean for project was 101.8 out of 100. Also, every group completed and reported all the steps related to computing methodology. The group evaluation process ensured the desired contributions from a student. Only two (out of 48) students contributed slightly less than the expected amount. Class mean for the four tutorials combined was 94.4 out of 100. Mean grades in Exam I and Exam II were 73 out of 96, and 51.8 out of 95, respectively.</td>
<td>Group evaluation aspect will be reiterated further. In Exam II, the students did not perform well in the multipart question related to numerical methods. I will share additional solved problems so that they have more practice.</td>
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<td>Learn about modeling of several biomedical processes in the areas of drug delivery and thermal therapy.</td>
<td>Primary (l-b)</td>
<td>Exams I and II, carrying 20% of the grade. Problems 1-3 in Exam I Problems 3-5,8 in Exam II.</td>
<td>Goal Met: Mean grades in Exam I and Exam II were 73 out of 96, and 51.8 out of 95, respectively.</td>
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*-Describe how the goal chosen by you has been met or surpassed in each ABET a-f category, eg., All students earned a quiz grade above 70%; Class grade on the relevant exam problem above 80%; All students achieved a grade above XX% on a case study relevant to the stated criteria. This must be a quantitative assessment.
1. In this offering of your course, have you made any of the following changes?

(a) Y / N - New material is being taught (if Y, please describe)
   Yes. I have formally included validation and optimization as sections.

(b) Y / N - I have changed the context of my course (if Y, please describe)
   No.

(c) Y / N - I have introduced updated material or examples (if Y, please describe)
   Yes. We have just completed the textbook for the course that involves substantial amount of new text material and problem sets at the end of 10 chapters, several of which were used as homework for the first time. Several new tutorials have been added and more of these are required to be completed by the students than in the previous years.

   The lectures were reorganized to closely follow the new text. Some important changes include removal of case studies as standalone items and instead highlight the principles contained in the case studies as general topics. For example, optimization and inverse problem are introduced as general concepts as opposed to discussing them as part of case studies.
(d) Y / N - Different or new technology is being used (if Y, please describe)
No. The software was changed in 2007, leading to redoing of the entire set of tutorials and much of the courseneotes.

2. Have you made any of the following changes to your course this term?

(e) Y / N - I have taken new steps to solicit student feedback (if Y, please describe)
The students are now required to fill in peer evaluations in connection with the group project, using the tool at https://www.catme.org/. While this is peer evaluation, it does bring up issues with any of the projects and whether they are enjoying the work and see the relevance of the projects to their career interests. I also do a midterm evaluation and correct any items brought about in the evaluations. This year I encouraged the students in person and through emails to complete the semester course evaluations. This is in addition to the informal feedback I get from other faculty.

(f) Y / N - I have made other changes (if Y, please describe)
The project report and its writing aspects are now overseen by Dr. Rick Evans of the College of Engineering Communications Program and the course now satisfies the Writing Requirement. Dr. Evans has produced handouts that are provided to the students with which he explains to the students how the content of their reports would relate to the context and how writing is to be approached in general. Dr. Evans also meets with each group individually at least once and provides detailed critique of their report, before the final submission.

3. What motivated you to make the changes described above? What impact have the changes had on the outcomes in your course?

2a)
The course has evolved over the years, starting from scratch. Initially, it was taught mostly from case studies which are published research papers. Routinely I distilled the kernels of simulation-based engineering from these research papers, appropriate in content and context for the undergraduate students. Validation and optimization are two such kernels that were previously taught only as part of one or two case studies, but now these two extremely important topics are highlighted better as standalone.

The students this year were a lot more sensitive to validation, for example. Perhaps the greatest impact is that every group has included validation in their report and one group even performed an experiment.
2c)
Introduction of computing of this nature to undergraduates is still very much evolving. There are not much details of how such a course is best approached. There are obviously no textbooks. We have been developing our text over a number of years and there was a clear need to complete the development as this is the only material from which the students could study (student feedback on the text provided valuable avenues to improve it).

The impact of the text on the course has been tremendous. The most important concepts in simulation-based engineering for undergraduates have been gelled (so the students and the instructor can focus on improving the learning of these concepts). I can assess such learning in the exams, homework and final project report. I can be much more direct in testing these concepts and ask questions that are at a significantly higher level.

As the concepts were better formed in developing the text, this needed to be reflected in the lecture notes. I give students a copy of the overheads (with missing items to be filled in during the lecture). Students prefer the lectures to follow the text. This led to the changes in the lecture notes. The course continued to run very smoothly with this change, even though the text was changed considerably.

2e)
Peer evaluation was motivated by occasional discontent in one or two groups that felt one or two members in the group did not contribute as much. Impact of the peer evaluation has been truly great in motivating everyone in the group.

2f)
The project reports developed by each group were quite substantial and I felt that this significant amount of writing should be recognized (perhaps by satisfying the Writing Requirement by the College). There was also room for improvement in the writing aspects of the reports. I approached Dr. Evans from the Engineering Writing Program who decided to take on the responsibility to oversee the writing component as he believed in "writing in context."

The writing aspect being administered by an appropriate expert (Dr. Evans) has two major impacts--1) Students learn how to approach writing in a particular context (as distinct from what is needed in this specific course); and 2) Significant improvements in the quality of the reports for this class. The latter can be seen by comparing the reports from this year with reports from 2006 and earlier.

4. **What student feedback have you received in response to the changes you have made?**

Important topics like validation, included more formally this year and followed by questions in the exam, have made the topics a natural component of student's thinking process in simulation-based engineering. They do not complain when they are asked to improve validation of their model. The students greatly enjoyed having a text and the smooth integration of important topics in text, lecture and project. This has been verbally mentioned by several students. Peer review process is greatly welcomed by the students as this ensures everyone's participation in the group without some of the group members having to deal with
those who may not comply. More formalized writing requirement is more work for the students but according to preliminary feedback, they welcome it as it does improve significantly their work.

5. **Are you planning changes in the course for the next semester?**
   No, except for developing some additional lecture slides that follow the book and some change in schedule that allows more time to provide feedback on the written report.

6. **What is the motivation for the planned changes? What impact(s) do you expect the changes to have on the outcomes in your course?**

   As the new text has developed, new overheads need to be developed from scratch. This has been mostly completed but 3 remaining chapters will have to be added. Checking the writing component needs to allow more time so that it does not overload Dr. Evans's schedule.
Appendix A. (for Spring 2007 Courses if taught)

Course Evaluation Supplemental Questions Related to ABET Outcomes (a) through (f)

Dept & Course No.: _______ Semester: ____________ Name of Instructor: ____________________

Please select (by checking the boxes) up to four (4) supplemental evaluation questions most appropriate to your course to be included in the end-of-semester on-line course evaluation by students. Please return your completed request to the Undergraduate Coordinator by the announced deadline.

Note that all the ABET Outcome questions will have the following instructions:
Answer: Check 1 through 5: ______ (1 = not helpful 5 = extremely helpful)

☐ (a) Did this course enhance your ability to apply knowledge of mathematics, science, and engineering?
☐ (b) Did this course enhance your ability to design and conduct experiments, as well as to analyze and interpret data?
☐ (c) Did this course enhance your ability to design a system, component, or process to meet desired needs?
☐ (d) Did this course enhance your ability to function on multi-disciplinary teams?
☐ (e) Did this course improve your ability to identify, formulate, and solve engineering problems?
☐ (f) Did this course advance your understanding of professional and ethical responsibility?
☐ (g) Did this course improve your ability to communicate effectively?
☐ (h) Did this course improve your ability to understand the impact of engineering solutions in a global and societal context?
☐ (i) Did this course promote recognition of the need for life-long learning?
☐ (j) Did this course enhance your knowledge of contemporary issues?
☐ (k) Did this course enhance your ability to use the techniques, skills, and modern engineering tools necessary for engineering practice?

☐ Select Question (ℓ-b) and/or (ℓ-e) as appropriate
☐ (ℓ-b) Did this course enhance your ability to integrate modern biology with engineering principles?
☐ (ℓ-e) Did this course enhance your ability to create sustainable solutions in the context of a complex natural environment

(Use the back of this sheet if more space is needed for alternative supplemental questions)
Appendix B

ABET Program Outcomes

Criterion 3. Program Outcomes and Assessment
Engineering programs must demonstrate that their graduates have:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Additional Outcome (l-b)* specific to Biological Engineering:
(l-b) An ability to integrate modern biology with engineering principles

Additional outcome (l-e)* specific to Environmental Engineering:
(l-e) an ability to create sustainable solutions in the context of a complex natural environment

*Some courses may find it appropriate to include both outcomes (l-b) and (l-e)