3.185 ABET Statements

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1 Subject objectives and outcomes

Objectives

1. Give students an understanding of conservation laws and constitutive equations as they apply to convective and diffusive (or viscous) transport of mass, heat and momentum.

   Outcomes On completion, students should be able to:

   (a) Use microscopic species/heat/mass/momentum balances to derive steady and unsteady differential equations for diffusion, heat conduction and fluid flow.

   (b) Use macroscopic balances to obtain simple solutions to larger-scale problems such as design of continuous flow reactors.

   (c) Have a qualitative understanding of turbulent flow phenomena, including:
   - Relation to the Reynolds number.
   - Mechanisms of enhanced effective viscosity, thermal conductivity, and diffusivity.
   - Turbulent kinetic energy and eddy length scales.
   - The k-ϵ model.

   (d) Develop the Bernoulli equation for "inviscid" flow in high Reynolds number situations.

2. Students should be able to solve simple 1-D diffusion, heat conduction or fluid flow problems using the transport equations.

   Outcomes

   (a) Calculate transport rates of species in mixed reaction/diffusion limited or convective mass transfer/diffusion limited situations, such as second phase layer growth (*e.g.* oxidation).

   (b) Use simple 1-D unsteady diffusion equation solutions, *e.g.* Gaussian, error function, Fourier series, to solve diffusion and heat conduction problems.

   (c) Use the Navier-Stokes equations to solve 1-D (Cartesian or cylindrical) steady-state fully-developed laminar flow problems.

   (d) Understand the similarity solution for a viscous boundary layer on a flat plate, and application to drag force and entrance length calculation.

   (e) Understand the phenomena involved in coupled fluid flow and heat conduction or diffusion, and their relation to heat and mass transfer coefficients, in situations of forced convection over a flat plate or natural convection near a vertical wall.

3. Develop the technique of dimensional analysis of problems, and illustrate its importance.

   Outcomes

   (a) Use dimensionless numbers throughout the course to condense transport behavior involving five or more parameters to simple expressions with just two or three parameters.

(b) Apply graphs and correlations of dimensionless parameters to transport problems for which there are empirical correlations but no analytical solutions, such as drag force on a sphere moving relative to a fluid, or heat transfer through a turbulent natural convection boundary layer.

(c) Understand the use of dimensionless numbers in physical modeling.

4. Teach students enough transport to be able to be conversant in the topic with chemical and mechanical (and other) engineers who spend more time learning these subjects and have access to more powerful tools, as students will likely work in multidisciplinary teams with such engineers throughout their careers.

   Outcomes

   (a) Understand the role of each of the terms in all of the transport equations presented in the subject, and how each affects the solution to a problem.

   (b) Use the explicit finite difference technique to approximately solve 1-D unsteady diffusion and heat conduction problems by means of a spreadsheet, and understand the relationship between the discretization and the stability and accuracy of the results.

   (c) Understand how the finite element method (FEM) is used to approximately solve equations or systems of equations in complex geometries, and be aware of some of its limitations.

   (d) Identify simple errors in FEM solutions of fluid flow problems.

2 Subject strategies

1. Prerequisite testing for mathematical skills, which often go under-utilized during the year or two between learning the material (typically during the freshman year) and applying it in this junior/senior level subject.

2. Lectures covering all of the phenomena listed above, with application to problems in materials processing and performance.

3. Weekly homework assignments in which students practice application of concepts learned in lecture to problems in materials processing and performance.

4. Test correction, in which students who have taken a mid-term test revisit their marked solutions during the subsequent recitation hour to correct mistakes and complete unfinished parts of the test.

3 Subject assessment methods

1. Portfolio analysis, based on the weekly homework assignments.

2. Testing, including two mid-term tests in mid October and late November, and a three-hour final exam during finals week. Each mid-term score is the weighted average of the in-lecture and corrected scores (see strategy 4 above). The final has closed-book and open-book components, the former focusing on qualitative understanding and the latter on quantitative problem solving.

3. Self assessment, in the forms of:

   - Index cards given out at each lecture on which students record the "muddiest" part of the lecture
   - Detailed subject evaluations in the middle and at the end of the semester.

4. Instructor's assessment, in the form of a memorandum assessing effectiveness in achieving the above objectives and outcomes, and making recommendations for changes to better achieve them.

4   Correlation Matrix

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3. Develop the technique of dimensional analysis of problems, and illustrate its importance.

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ABET criteria

a. Ability to apply knowledge of mathematics, science, and engineering

b. Ability to design and conduct experiments, as well as to analyze and interpret data

c. Ability to design a system, component or process to meet desired needs

d. Ability to function on multi-disciplinary teams

e. Ability to identify, formulate, and solve engineering problems

f. Understanding of professional and ethical responsibility

g. Ability to communicate effectively

h. The broad education necessary to understand the impact of engineering solutions in a global and societal context

i. recognition of the need for, and an ability to engage in life-long learning

j. Knowledge of contemporary issues

k. Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

ABET criterion	a	b	c	d	e	f	g	h	i	j	k
Objective 1	H		H		H			M		M	H
Objective 2	H		H		H						H
Objective 3	H		H		H						H
Objective 4	M		M	M	M			M	M	M	H

Table 1: 3.185 Correlation Matrix

5   Reflective Memorandum

An unfortunate trend for the past two years seems to be "feature creep", a term borrowed from the software industry and used to describe the tendency of software engineers to add just one more feature here, just one more capability there, until the whole program becomes unmanageably large and unwieldy. In 3.185, this means that each semester I add just one more topic in this section, just one more explanation for that phenomenon, etc., so these new "features" of the subject squeeze out important topics. For example, last year when teaching diffusion, I just taught the Fourier series for infinite and finite symmetric ($\frac{1}{2}$-period) systems; this year I added $\frac{1}{4}$-period systems to explain the problem on last year's exam 1, which appeared on a problem set. Other items taught more slowly this year prevented us from covering high-temperature trends in water heat transfer coefficients, such as nucleate boiling and film boiling.

On the other hand, in both 2002 and 2003, we concluded the semester with the same topic, which was the Bernoulli equation. I think that both Bernoulli and natural convection were covered better this year than last, because of a new way of explaining the Grashof number as the "natural convection Reynolds number", but I still need to work on a better explanation for the rate of growth of natural convection boundary layers. Neither 2002 nor 2003 included continuous flow reactors, which are an interesting and important topic; we have never covered flow through porous media; but I think this was due to the introduction of "muddy cards" in 2002.

Speaking of muddy cards, this semester's class was noticeably more participatory than last year's, both in terms of muddy cards and verbal questions in class. Since Christine Ortiz also observed this trend in 3.11, I believe that it's a real change, this year's class is just that much better in that regard.

Unfortunately, the textbook change was not as successful as was hoped. Welty, Wicks, Wilson and Rorrer did a number of things better, such as visualizations and viscosity notation; some things just as badly, most notably the order of topics which remains inappropriate for this subject; and some things less well, such as the unconventional shear stress convention used for fluids. Based on this, I cannot recommend this text for next year's Materials Processing subject.

As a final (no pun intended) commentary on this semester, the final exam was again a bit too hard this year. Part A (closed-book) was appropriate in length and difficulty, and will likely have one or two 100% scores. But Part B (open-book) was too long, a bit on the hard side, and most importantly, not well understood. For example, it seems that most students saw the ladle graph and immediately assumed that the whole problem used the Bernoulli equation; a hint about adapting Hägen-Poiseuille would have helped a lot. And students did not seem to understand what the "Complete Idiot's Guide" essay was asking for; a reference back to the recipes in a Part A problem would have helped a great deal. The basic problem is that I need to not focus on stretching the students to "See how much you can do with the transport you've learned," because those who don't finish it will feel like they haven't learned much at all.

Next year, this subject will go away and be replaced by Materials Processing, which is supposed to be 3.185 plus economics plus a lab, with greater focus on the processes themselves. Good grief, doesn't 3.185 have enough material in it already? But that's the mandate from the department, so I'll have to live with it. The question then becomes, what to eliminate?

- Discard all of diffusion. This is covered in 3.022, the new kinetics subject. But then, it was also covered in 3.01 under the old curriculum, and yet students appreciated the re-coverage, both to review the material and to present it in a 3.185 way. Thing is, although it would seem eliminating diffusion could save a bunch of lectures, in fact, the first heat conduction lecture just recaps all of the diffusion material for conduction, so we'll need to teach that stuff anyway—if we want it to be covered...

- Discard some of diffusion. The erf solutions are too important to discard, but Fourier series will probably have to go—too bad, because that was perhaps the most elegant solution, and helped considerably in the explanation of the steady-state timescale. But what else can go? Layer growth is very important; perhaps it can go in kinetics, and we can do conduction-limited layer growth by analogy to that. Dimensional analysis can *NOT* be removed, that is an extremely important concept which must be covered at some point prior to student learning about transport.

- Give up trying to explain Navier-Stokes. Just face the fact that students will never understand the nature of the convective momentum transport terms, and treat N-S as some mythical equation which

they might hope to understand if they take 10.301 or 2.005 but which we just won't do here. Never mind that N-S is the underpinning of everything from convective heat and mass transport to Bernoulli to the thing solved by a myriad finite element simulations they'll want to do for everything from casting and injection molding to CVD, etc.

So these are some ideas on what to give up. Now what should be added, how should things be explained in light of these realities, and what will be added?

- Treat flow phenomenologically, like the viscous component proportional to $\mu U/L$ and the kinetic energy component proportional to $\frac{1}{2}\rho U^2$. Skip the Navier-Stokes section and go straight from viscous transfer to either Bernoulli via control volumes, or drag force in tubes, flat plates, spheres and porous media.

- Economics: I can think of three topics, which are batch and continuous flow reactors, how they lead into cost modeling, and input/output modeling.

- Labs: look at `efluids.com` for inspiration, and come up with some simple lab concepts.

For lectures, I envision a good amount of "chalk-and-talk" because that's good pedagogy, but with more computer visualizations and movies and such to enhance it.

So in any case, that's 3.185, and how it's going to change to 3.044, Materials Processing, as we move forward. The reinvention will help to clear out a lot of the "feature creep", but needs to be done carefully so the result is coherent and effective in reaching its teaching goals. I look forward to the challenge!