TEACHING ENGINEERING IN THE 21ST CENTURY WITH A 12TH-CENTURY TEACHING MODEL:

HOW BRIGHT IS THAT?

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If you took a stroll down a hall of the University of Bologna in the 12th Century and looked into random doorways, you would have seen professors holding forth in Latin to rooms full of bored-looking students. The professors would be droning on interminably in language few of the students could understand, perhaps occasionally asking questions, getting no responses, and providing the answers themselves. You might see a few students jotting down notes on recycled parchment, a few more sneaking occasional bites of the cold pizza slices concealed in their academic robes, some sleeping, and most just staring vacantly, inwardly cursing the fact that iPods would not become readily available for another 800 years. Toward the end of the lecture, one student would ask “Professore, siamo responábili per tutta questa roba nell’esame?” and that would be the only active student involvement in the class. Eventually the class would be released, and the students would leave grumbling to each other about the 150 pages of reading assigned for the next period and expressing gratitude for the Cliffs Notes version of the text.

American engineering education doesn’t *exactly* follow that model. For one thing, the only engineering professor in the Western Hemisphere—and maybe in the world—who could lecture in Latin was Rutherford Aris, and he’s deceased. Hard drives have replaced parchment, baseball caps and jeans have replaced caps and gowns, and (this is a huge difference) students in Bologna actually had a lot of power, including the responsibility of hiring professors and the right to fire them if their performance was considered unsatisfactory. Leaving those differences aside, however, the fact is that things haven’t changed all that much since the 12th century. If you walk down the hall of an early-21st-century engineering school and look into random doorways, there’s a good chance you’ll see the descendants of those Bolognesi staring vacantly,

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snacking, and sleeping as their professors drone on incessantly in what might as well be Latin and fill the board or projector screen with Latin and Greek symbols that have little or no obvious relevance to anything the students know or care about.

Twenty years ago that's *all* you would have seen in those classrooms, with very few exceptions. Now, however, in some departments at some schools you can find a significant number of classrooms in which other things are happening. You might get the first signal of a difference before you ever get to the doorway, when from down the hall you hear things that are never heard in a traditional engineering classroom—sounds of conversation, discussion, and argument, possibly punctuated by laughter, alternating with periods of silence. If you look into the room for awhile you would see traditional classroom moments alternating with brief periods in which students are doing things individually or in pairs or small groups—answering questions, completing the next steps of derivations or problem solutions, troubleshooting, predicting, estimating, critiquing, interpreting, modeling, designing, formulating questions, and summarizing. At any given moment the professor might be in front of the class lecturing and answering questions, or quietly observing the activity, or wandering around the room interacting with individual students and student groups. Unlike the situation in the traditional classroom, many people—including the professor—would appear to be enjoying themselves. Also unlike the traditional classroom, most of the students enrolled in the course would actually be there.

If you have been firmly entrenched in the traditional paradigm I would encourage you to try branching out, but I would also suggest taking it easy.

If you enquired further into how courses are run in that department, you would see further evidence of two competing models—one that would seem familiar to our 12th-Century scholars and one dramatically different. In one set of courses, the professor would spend a great deal of class time lecturing on the basic facts, formulas, and problem-solving algorithms that comprise the course material, and would then give assignments and tests calling on the students to demonstrate their ability to recite the facts, execute the formulas, and implement the algorithms. In the other courses, the students would be presented with problems *before* they are told everything they need to know to determine the solutions. They would then work—sometimes individually and sometimes in teams—to identify what they know and what they need to find out, do research, formulate and test hypotheses, and arrive at solutions. The professor would still be there to provide information and guidance, but formal instruction would only occur when the students had established a need to know something to progress with their work.

So why the change? What is the answer to the traditional professor's traditional defense of tradition: "It's been done this way for decades or centuries and has worked fine," or implicitly, "This is how I was taught, and look how well *I* turned out!"

There are several answers, which would take much longer to present completely than I have in this little piece, so I'll only give brief suggestions of what they are and point to references where the whole story can be found. First, if "working fine" means turning out excellent engineers who have made brilliant creative contributions to industry and society, that has certainly happened over the centuries. The issue, however, is whether it happened because of traditional higher education or despite it. There is compelling evidence that the latter may be the case. Take Europe, for example. In the traditional European system of higher education that has prevailed for centuries, the professor is a godlike figure who lectures to students and has little or nothing more to do with them. The students may or may not choose to attend the lectures—if the professor is a particularly skilled lecturer they attend, otherwise most don't.

You might argue that this system led to the wondrous scientific advances of the Renaissance and the Enlightenment and the giant technological leaps of the industrial revolution, but I would quarrel with that argument. If you admit only the cream of the crop of a nation's youth (which universities in Europe and America did until fairly recently), it almost doesn't matter what you do or don't do in the classroom. You could simply hand out syllabi and lists of references and tell the students that they will be examined at the end of the year, and then do nothing else—no lectures, no homework, no tests except the final exam—and most students would manage to learn the material and pass the exam, and the few geniuses among them would go on to make their brilliant contributions, especially if they were clever enough to apprentice themselves to masters from the previous generation.

In short, professors who provide only traditional lecture-based instruction are largely irrelevant to the real learning process for top students. Good lecturers can certainly enrich their classroom experience, but they will learn with or without that enrichment. On the other hand, if you are trying to educate a broad segment of the population—as we are now doing in the United States—many students can't make it with only the support that traditional instruction provides, and the consequence is the attrition of 50% and higher that we routinely see in engineering.

Another argument for change is that unlike our antecedents in the Middle Ages, we now know a lot from cognition research about how people learn and the instructional conditions that facilitate learning [see the reference by Bransford, *et al.*, in the bibliography], and everything we know supports the proposition that the traditional lecture-homework-test paradigm of engineering education is simply ineffective—good students learn despite it, and weaker students who could make excellent engineers frequently cannot survive it. The alternative instructional environment supported by the research is quite different. Here are some of the things teachers do in that environment, contrasted with what they do in the traditional approach.

- **T:** (Traditional) Establish a syllabus assuming that all necessary prerequisite knowledge is known, and march through it.

  A: (Alternative) Find out at the beginning of a course what most of the students know and don't know and what misconceptions they have about the subject, and start teaching from that point. (This approach is known as *constructivist teaching*.)

- **T:** Assume all students with the ability to succeed in the profession for which they are being educated are basically alike (specifically, like the professor) and learn in the same way, and teach accordingly.

  A: Recognize that good students vary considerably in motivation, cultural background, interests, and learning style, and teach accordingly.

- **T:** Focus on facts, formulas, and algorithms for solving well-structured closed-ended single-discipline problems.

  A: Supplement the traditional content with training in critical and creative thinking, methods of solving ill-structured open-ended multidisciplinary problems (which tend to be what practicing engineers spend most of their time dealing with), and professional skills such as communication, teamwork, and project management.

- **T:** Cover basic knowledge (facts, algorithms, and theories) in lectures, then assign problems that call for implementation of the knowledge, then illustrate the knowledge in laboratories.

  A: Recognize that students learn best when they perceive a need to know the material being taught. Start with realistic complex problems, let students establish what they know and what they need to find out, and then guide them in finding it out by providing a combination of resources (which may include mini-lectures and integrated hands-on or simulated experiments) and guidance on performing library and Internet research. This is *inductive teaching* and has a number of variations, including *problem-based learning, project-based learning, guided inquiry, discovery learning*, and *just-in-time teaching.*

- **T:** In class, present information, derive formulas, and illustrate problem-solving procedures in lectures, boardwork, and overheads or PowerPoint images, occasionally asking questions and responding to questions students might ask.

  A: In addition to lecturing, have students work individually and in small groups on brief course-related activities, such as answering questions, setting up problem solutions, completing steps in derivations, interpreting observations or experimental data, estimating, predicting, brainstorming, troubleshooting . . . . Call on several students for responses at the conclusion of each activity, then invite volunteers to provide more responses to open-ended questions, and proceed with the lesson when the desired points have been made. This is *active learning*.

- **T:** Require students to do all of their work individually.

  A: Assign a combination of individual work and teamwork, structuring the latter to provide assurances of individual accountability for all the work done and following other procedures known to promote good teamwork skills (including communication, leadership, project management, time management, and conflict resolution skills). This is *cooperative learning.*

- **T:** Tell the students they are responsible for everything in the text, lectures, and homework, and make up exams that draw on those sources, including some problems with twists that the students have not seen before and have to figure out on the spot. (Those problems are there to see if the students "know how to think"). It is up to the students to guess what the instructor thinks is important enough to include on a test.

A: Write comprehensive *instructional objectives* that list the things the students should be able to do (identify, explain, calculate, model, design, critique . . .) to demonstrate that they have satisfactorily mastered the knowledge and skills the instructor wants them to master, including high-level thinking and problem-solving skills. Make the objectives available to the students, ideally in the form of study guides for tests. Design in-class activities and homework to provide practice in the desired skills, and make the tests specific instances of a subset of the instructional objectives.

Instructors who are unfamiliar with the latter approach imagine that they will have to list thousands of objectives to be comprehensive, but this is not the case—a two-sided sheet of paper is normally sufficient to list all of the objectives that might be drawn upon to construct a midsemester test.

Entire articles and books can be—and have been—written on each of the given alternative teaching methods, describing how to implement them and summarizing the research base that demonstrates their superiority to the traditional approach. The bibliography at the conclusion of this paper suggests starting points for interested readers.

If you have been firmly entrenched in the traditional paradigm I would encourage you to try branching out, but I would also suggest taking it easy. Going directly from a traditional teaching model to a full-bore active/cooperative/problem-based learning paradigm starting next Monday is probably not a good idea—the amount of preparation required and the student resistance that might erupt could be overwhelming. A better approach is to make the change gradually, perhaps by doing a few small-group exercises in lectures, using a problem-based approach to teach one or two topics, and writing instructional objectives for one midterm test. In subsequent courses, increase your use of the new methods, never departing too much from your comfort zone, and you should see your students' learning steadily increasing. After all, it took us 800 years to get from Bologna to where we are now; if it takes you a few years to get where you want to be, the sky won't fall.

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