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Changing Pedagogy: What Our Students Say

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While the days of the solitary professor lecturing in a cloud of chalk dust (or a blur of viewgraphs) are not gone, a noticeable change is occurring in the engineering classroom. Although some aspects of this evolution are due to technology, many of these changes are the result of continued progress in the understanding of how we learn. Educational research has led to the recognition of several principles of effective teaching[1], and these principles are now finding their way into our classrooms.

Our Department is one of the leaders in educational innovation at M.I.T. The Department's strategic plan in 1998 recognized the need for changing not only what we teach but also how we teach. Since that time, I have been actively involved in reforming the pedagogy in the courses I teach. In this article, I look back at what the students have said about the pedagogy, both in its current form and during its evolution. What I have observed with our students, to no surprise, is that they recognize the potential for effective pedagogy even when hampered with an initially poor implementation. And, when well implemented, our students find the new pedagogy highly effective.

Changing Pedagogy

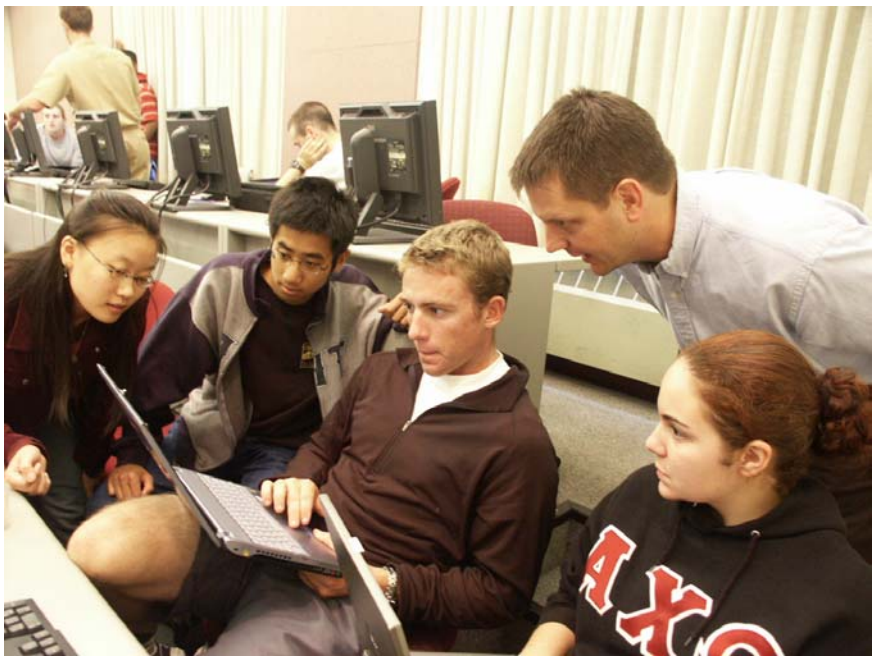
One of the subjects I teach is 16.100 Aerodynamics. 16.100 is a junior/senior-level course with a typical enrollment of around 40 students. While not required, it is one of a handful of courses the Aero-Astro students can select from to fulfill their undergraduate requirements. I have made substantial changes to this subject trying to incorporate the best understanding of effective pedagogy[2]. Prior to 1999, the course was a fairly typical undergraduate engineering course with lectures, recitation, weekly homework assignments, a small end-of-semester design project, and a few written exams. The current version of 16.100 includes:

- **Concept-based lectures with real-time feedback.** Educational research has shown that in order for students to develop a strong conceptual framework, misconceptions that have occurred in previous learning must be addressed such that students become dissatisfied with their understanding[1]. To do this, I follow an approach developed by Prof. Eric Mazur at Harvard called peer instruction[3,4]. In this approach, two or three multiple choice concept questions are given in a typical one-hour lecture. These questions are designed to include the important concepts of the subject and their common misconceptions. Using a personal handheld remote, students select an answer after a couple of minutes of independent reflection. Then, depending on the responses, students are given time to interact with each other to discuss their answers and/or a short lecture on the concept is given. The educational research shows that this type of active learning not only can improve student understanding but also can increase confidence, enjoyment of a subject, and inter-personal skills[5]. Within our Department, the peer instruction approach was first used extensively in our core

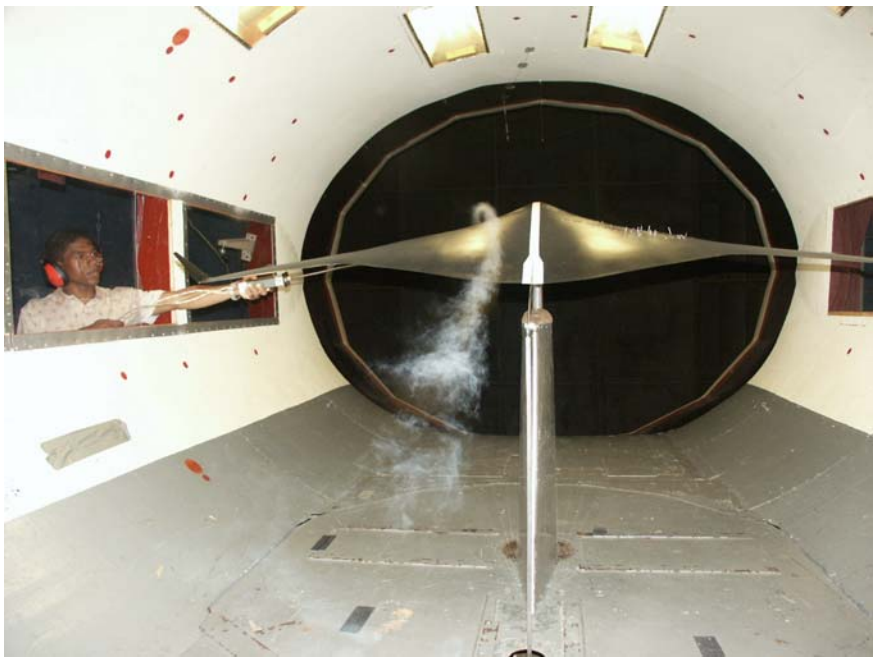
Department subject Unified Engineering, and was described in detail by Prof. Steve Hall in the previous Aero/Astro review.

- **Weekly (graded) homeworks on material given prior to being discussed in class.** In order to increase the effectiveness of the concept-based lecturing, students need to have engaged the material prior to class. Without this prior engagement, students may not have sufficient background in the material to even understand the conceptual questions being asked. Traditionally, engineering courses almost exclusively assign homework after the concepts have been presented in class. However, to improve student preparation, I give homework assignments (with appropriate reading) on material prior to in-class discussion. These homeworks are essentially the same difficulty of homework I would have given after a set of lectures in the traditional pedagogy. With this preparation, the classroom becomes an interactive environment where students are ready to discuss the conceptual difficulties they have faced and have begun to develop a common language to have this discussion.

- **A semester long, team-based analysis and design of an aircraft.** Typically, aerodynamics and other advanced engineering topics are taught with a significant focus on theory but little opportunity to apply theory especially to problems that approach the complexity faced in the design of modern aircraft. As a result, students perceive they are learning material 'just-in-case' they may need it later in their careers. In the project-based approach used in 16.100, the knowledge is immediately being applied. Furthermore, the use of a semester-long project provides a context for learning the technical fundamentals as proposed in our Department's Conceive-Design-Implement-Operate (CDIO) initiative. Over the past four years, two design projects have been developed: one based on a military fighter aircraft (in collaboration with Michael Love of Lockheed Martin) and another on a blended-wing body commercial transport aircraft (in collaboration with Bob Liebeck of The Boeing Company and a Professor of the Practice in our Department). Both of these projects have an initial modeling phase in which student teams develop and validate aerodynamic models for a baseline



A student project team discusses the aerodynamic analysis of a blended-wing body aircraft with Prof. Darmofal during a weekly project work session.



Students perform flow visualization to over a blended-wing body aircraft model in the Wright Brothers Wind Tunnel.

configuration using a combination of theory, wind tunnel testing, and computer simulation. This modeling phase is followed by a design phase in which the models are used to improve the aerodynamic performance.

- **Oral examinations.** In addition to changing the in-class pedagogy, I have also modified the exams from a written to an oral format. While written exams can only analyze the information that appears on paper, i.e. the final outputs of a student's thought process, an oral exam is an *active* assessment that can provide great insight into how students understand and relate concepts. Furthermore, practicing engineers are faced daily with the real-time need to apply rational arguments based on fundamental concepts. By using oral exams, a student's ability to construct sound conceptual arguments can be readily assessed.

What Students Say

During this evolution of 16.100, student evaluation data from end-of-semester surveys has been used to assess the effectiveness of the pedagogy and improve its implementation. The evaluations consisted of quantitative ratings of the effectiveness of the course pedagogy, as well as open-response questions. The open-response questions asked 'What were the best parts of the course?' as well as 'How could the course be improved?' Here's a synopsis of what the students have said:

	Homework & Textbook	Lecture	Project
Post 2000	2.78	2.76	2.53
2000	2.48	2.14	2.61

Table 1: Average student ratings of the effectiveness of different aspects of the course pedagogy for 2000 and post-2000 (2001-2003) semesters. 1= not effective, 2 = effective, and 3 = very effective

- **The new pedagogy, in its final form, is consistently rated as highly effective.** The past three years (Fall 2001 – 2003), the pedagogy as described above has remained nearly the same with only minor adjustments. As shown in Table 1, the mean student ratings of the effectiveness of the pedagogy are all between effective to very effective.

- **Challenging pre-class homework increases the effectiveness of lecture.** In the Fall 2000 semester, while the pedagogy was as described above, the pre-class homeworks were designed to encourage reading but did not require significant engagement of the material. As a result, the students were not sufficiently prepared for in-class active learning and found the overall approach to be less effective. In fact, the student feedback from the Fall 2000 course evaluations led directly to the decision to increase the difficulty of the homeworks. The post 2000 data shows a statistically-significant increase in the mean effectiveness of not only the homework but also the lectures compared to Fall 2000 (see Table 1).

- **A learning transition occurs over the length of the semester.** The open-response questions show that students are often initially hesitant about pre-class homework, but by the end of the semester they recognize the benefits of this technique. Some of the comments include:

  - *I was initially opposed to the idea that I had to do reading & homework before we ever covered the subjects. Once I transitioned I realized that it made learning so much easier!!*

  - *I was skeptical at first of new techniques like [concept questions], homework on material that hasn't been learned in lecture. In the end, it worked out very well. This has been a course where I really felt like I got my money's worth.*

  - *Prof. Darmofal forces you to learn the subject material by assigning homework that he has not covered in lecture, therefore I have to force myself to read the text and go to office hours. When he does go over in lecture after the Pset is due, I did absorb the material much better.*

  - *Doing homework before the lectures is good… makes actual learning in lectures possible.*

  The comments also reinforce the link between the pre-class homework and the effectiveness of the lectures.

- **The effective implementation of the team project is difficult.** One of the most challenging aspects of the new pedagogy has been the implementation of the team project. In the first place, the project has multiple facets (in particular the wind tunnel experiments and the computational simulations) that must be successfully managed. Furthermore, keeping ten or more teams of four students functioning effectively can be highly time-consuming for both the faculty and the students. The open-response questions for the past three years clearly show both the benefits as well as the difficulties of the team project. During this time, 31 positive comments were made about the project with only 2 negative comments; however, 29 students suggested the need to improve the implementation. For example, typical comments include:

- *I think the team projects are really good. There are some kinks which need to be worked out and possibly explained sooner, but they really bring us to an understanding of what elements are necessary to incorporate theory into design*

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- *My group floundered for a while with the project. In the end we got everything to come together, but it was tough to get through. I'm not sure that I would have wanted it any other way, now that I look back on it. I learn best when I struggle with material for a while, provided I have enough time to finally understand it. I had just enough time for the project.*

- *Although the project was extremly time consuming, it was fun to be able to apply what we were learning to a real aero problem.*

As our Department continues to incorporate CDIO throughout the undergraduate curriculum, the effective use of projects will be a challenging issue to address.

- **Oral exams are an effective assessment strategy.** Many students find the oral exam to be a much more accurate representation of their understanding than more traditional written exams. In fact, several students have said that the oral exams were the best parts of the course. Of the 21 comments made about oral exams in the open response evaluations, 19 were favorable, only one was negative, and one suggested a modified implementation. Some typical comments are:

  - *The oral exam was a different learning assessment approach that I liked a lot.*

  - *I really like oral exams that stress conceptual knowledge.*

  - *The oral exams are an excellent measure of understanding.*

  - *Oral exams [are the best part of the subject], I think these gave a good opportunity to show what you understand.*

  - *I really like the idea of the oral final. Even though it is scary, it really shows how much you know about the subject, better than any exam would.*

Outlook

Pedagogical reform will continue as the findings of educational research impact engineering campuses across the country. In our Department, this impact is already being felt. The voices of our students show that these new pedagogies, while challenging to implement, can lead to a more effective learning environment.

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