

Active Engagement Pedagogy for an Introductory Solid Mechanics Course

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Abstract

Advances in information technology (IT) are enabling universities to effectively integrate computers into the curriculum. An initiative to comprehensively transform the pedagogical format of 2.001-Mechanics and Materials I, a sophomore-level Mechanical Engineering course at the Massachusetts Institute of Technology (MIT), has been undertaken. The new teaching paradigm, in contrast with the traditional lecture format, incorporates components of faculty-facilitated learning, hands-on experiments, group discussion, web-enabled exploration, and peer learning. A major element of this educational reform is a collection of Web-based learning modules. The new teaching format is enabled by a mobile, wireless computing initiative that provides all students with laptop computers and a new classroom, built to meet the requirements of the new paradigm. Students were first taught using the new teaching methodology in fall 2001. This paper will discuss the components of the new pedagogy and future steps in developing the course.

I Pedagogy

We have undertaken an initiative to examine the effectiveness of altering the teaching/learning paradigm in core undergraduate Mechanical Engineering courses. Mechanics and Materials I: Introduction to Solid Mechanics (MIT course number 2.001) is being used as a pilot test in determining whether an active engagement pedagogy will be effective in enhancing a student's:

- physical understanding of the course material (deep learning)
- willingness to explore a new phenomenon (curiosity)
- inclination to engage in technical discourse (communication)
- retention of “learned” material, and ability to apply this new knowledge in subsequent courses and settings (retention)
- enthusiasm and satisfaction with learning engineering (enthusiasm)

The major thrusts of the active engagement pedagogy are cooperative and discovery-based learning. Cooperative learning exposes students to teamwork, allows them to reap the benefits of peer engagement, and creates an atmosphere requiring technical discourse of all students. In discovery-based learning, students learn through a combination of physical and computer-based experimentation; the decision to include both physical experiments and computer models was a conscious one.

Students have extensive experience and comfort with computers, and learning using computers. We are striving to take advantage of this comfort level by developing Web-based learning mod-

ules which they can actively engage¹. These modules have been created for each of the major course topics and serve multiple roles: an interactive learning tool, a basis for class discussion, a study aid, an in-class faculty-student communicator. In this manner, these modules enhance student communication, retention, and enthusiasm. Students are furnished with laptop computers, which allow them to engage the Web-based learning modules both in class and at their own convenience.

Students need more physical interaction due to the reduction of such experiences in life; such interaction enables students to develop a “feel” for phenomena. Desktop experiments that demonstrate particular phenomena represent the physical interaction of the new course. The experiments enable the students to physically explore a phenomenon prior to seeing the underlying theory and equations. These experiments serve to build in the students: deep learning, curiosity, communication, and enthusiasm.

The classroom in which the course is taught has been rebuilt to align with the new pedagogy; this room facilitates both laptop computer use and physical experimentation. The elements of the new course are described in the next three sections.

II Web-based Learning Modules

This course will consist of eleven Web-based learning modules in total: Equilibrium, Friction, Axial Force-Deformation, Truss Structures, Multiaxial Stress-Strain, Linear Thermo-Elasticity, Bending, Buckling, Torsion, Energy Methods, and Materials Selection. Four of these modules - Equilibrium, Friction, Truss Structures, and Bending - have been completed and three were used in teaching the course in fall 2001. Each module consists of 8 parts: an online lecture, an electronic textbook, a library of real-world examples, an interactive design simulation, a dynamic database-enabled quiz, a reference section, an in-depth case study, and a design exercise. The following sections describe the components of each of the modules in detail².

a) Simulation

Properly designed simulations can be very useful in developing students' conceptual understanding of scientific topics³ and this is the intent, in this case, of the Beam Bending simulation. This investigative tool allows students to construct and compare two beams of different types subject to various constraints (Fig.1). Specifically they can vary material, cross-section, dimensions, boundary conditions, load types, load magnitudes, and load locations. Based on student inputs, the simulation displays the boundary and loading conditions of the beam. Below this are graphs plotting the internal shear force, internal bending moment, deflection, and stress distribution as a function of axial position.

The layout of these graphs above one another allows students to understand how these different quantities are related to one another, enabling the students to develop a conceptual understanding of what parameters affect beam behavior. In addition, as students gain a better understanding of the topic, they are asked to use this simulation as a tool in a design problem presented to them.

The simulations are based on Java technology, which was chosen for several reasons⁴. First, Java applets can call from a powerful suite of features, enabling an applet to be almost as powerful as a standalone application. Secondly, applets run in Web browsers by nature, which makes their inte-

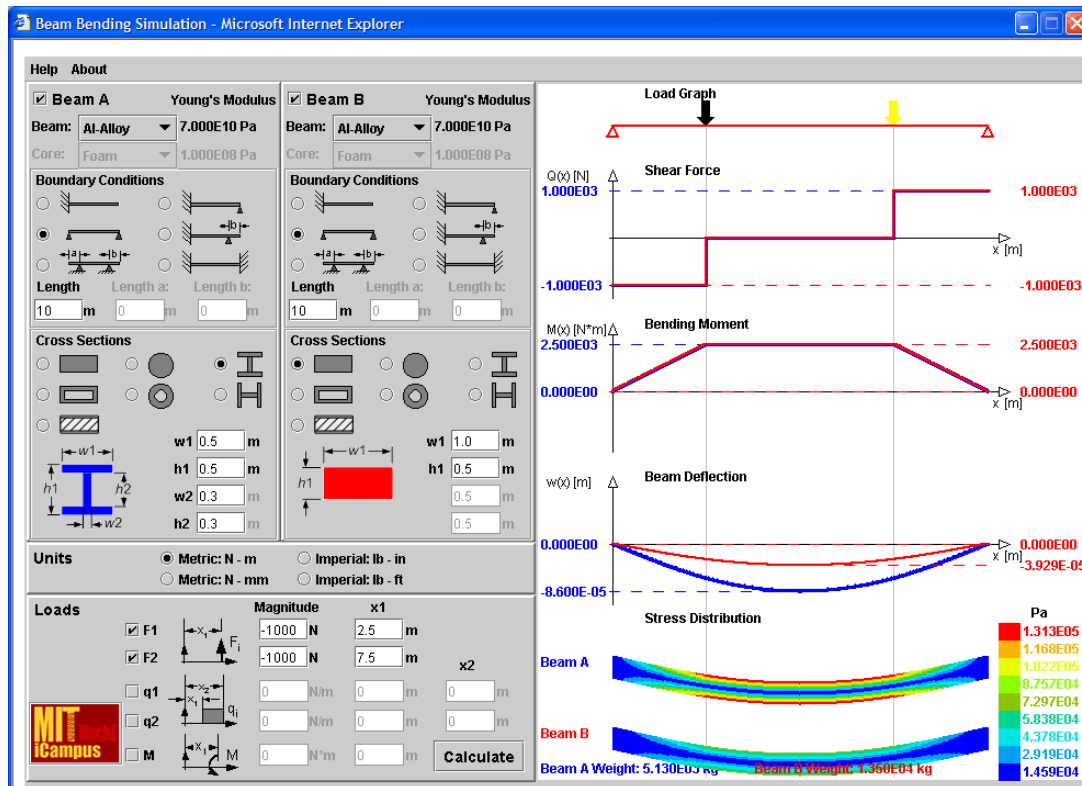


Fig. 1 Beam Bending simulation

gration into the web module quite easy. This is a proven concept: Java applets have already been used successfully in mechanics education⁵. Consistency across platforms^{*} is achieved by relying on the 1.30 version of the Java plug-in, a tool that, if necessary, downloads and installs the correct version of the Java Runtime environment.

An account of a lecture that used a simulation is given here. After a brief discussion on the design of truss bridges at the beginning of the 2 hour period, the instructor introduced a design problem, that of a pedestrian bridge. Students then worked in pairs on the design exercise, using the Truss Structures simulation as an aid (Fig.2); they also made use of a desktop experiment which allowed them to understand the mechanisms of truss bridges at a conceptual level.

The simulation-based exercise introduced students to the process of design, and to the concepts of safety factors and buckling. It also developed a better understanding of the design of truss structures. After approximately 1 ½ hours of work, the three lightest designs were presented by students. Each pair of students connected their laptop to the room projector, displayed their design, and explained their design rationale to the class (Fig.3). At the end of class, student teams electronically submitted the portion of their report that they had completed. Each team then completed the full design report at home and handed them in one week later.

*. Macintosh computers will need to have OS X installed.



Fig. 2 Two students working together on their truss design using the Truss Structures simulation.

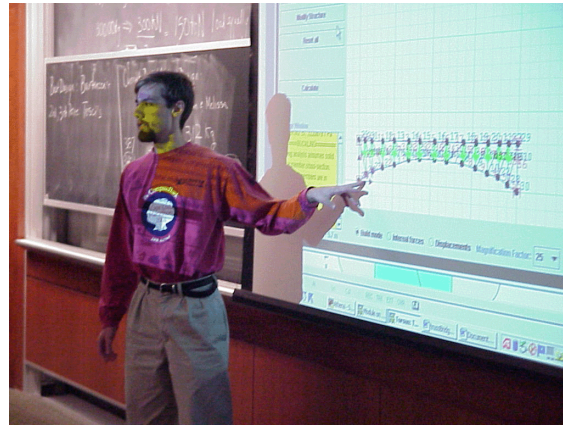


Fig. 3 A student presents his "lightest design" to the class using his laptop and the classroom's projection system.

b) Online Lectures

Online lectures are primarily intended as a supplemental resource, allowing the students to review material at their own convenience. The Web-based lectures are important because they afford students of different learning styles the same ability to learn the material⁶. Our general approach is based on the online lecture model of Lozano-Perez⁷. The lectures are a narrated series of images; a custom tool allows the conversion of a PowerPoint file to this Web-specific format⁸. Text of the narration is also offered for students who are hearing-impaired or simply prefer to skip the audio portion. The online lectures present the material covered in traditional class lectures. This format was chosen over a video recorded format for several reasons. First, video downloads tend to be slow, and streaming video requires a separate, dedicated video server, which can be expensive and difficult to maintain. Secondly, viewing the notes in this clear format is more value-added than watching a video of an instructor writing on a chalkboard, and also enables a certain level of interactivity with the lecture. Lastly, despite the initial time investment, this format enables a quick and reliable system for updating lectures as time progresses. Changing a portion of a video lecture for a future class is not only time-consuming; it may necessitate that the entire lecture be redone. In the future, the lectures will take the form of narrated Flash animations[†]. This will enable the online lectures to leverage the full power of IT, through the inclusion of animations and movie clips.

c) Electronic Textbook

The electronic textbook section contains a much more detailed presentation of the material and goes beyond what is covered in lecture. These pages serve to analytically examine the principles and equations underlying a specific topic, similar to a paper-based textbook. This system, however, has many advantages over a traditional textbook. First, the use of hyperlinks allows us to create a set of core documents that contain only essential material. Detailed derivations are generally provided through hyperlinks - as are the simulation, reference material, real world examples, and the case study - allowing the students to easily navigate and quickly find relevant material.

†. Flash is a Macromedia format that plays in most Web browsers

Given that engineering education builds heavily on previously learned material, providing such navigation aid makes the learning process considerably easier. Additionally, the Web allows for the inclusion of many multimedia objects, such as animations and movie clips that can illustrate points more clearly than any description.

d) Real World Examples

The real world examples section seeks to strengthen a major weakness that is often encountered in an engineering class: the inability of students to take a real problem, make reasonable abstractions and simplifications, and solve the problem with the tools acquired. The ability to reduce a real problem to a model is an area where students tend to be lacking, because they are generally used to the schematics provided in textbook problems. We have therefore created an ASP (Active Server Pages) utility that allows users to scroll through a library of photographs of real world examples. Each of these photographs is tied to a description of the situation (Fig.4). Students can then view a schematic drawing of the real world system (Fig.5), along with a description of the schematic model and assumptions made in creating it. Students are challenged to determine a mechanical model for solving a problem and can then review the model. In appropriate cases, links are included to other portions of the site, such as the case study, where the examples are studies to completion. The real world examples section gains importance when students are later presented with a design problem.

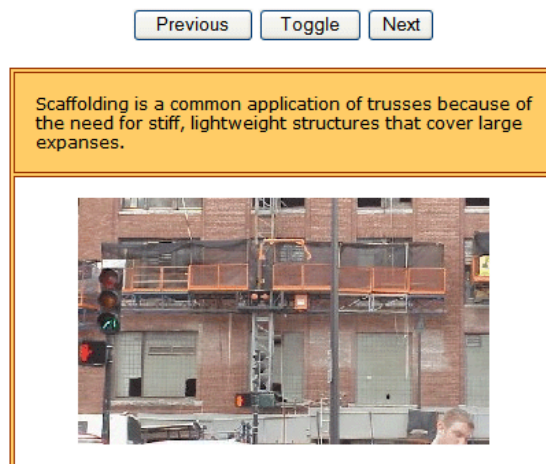


Fig. 4 Real world example showing building scaffolding.

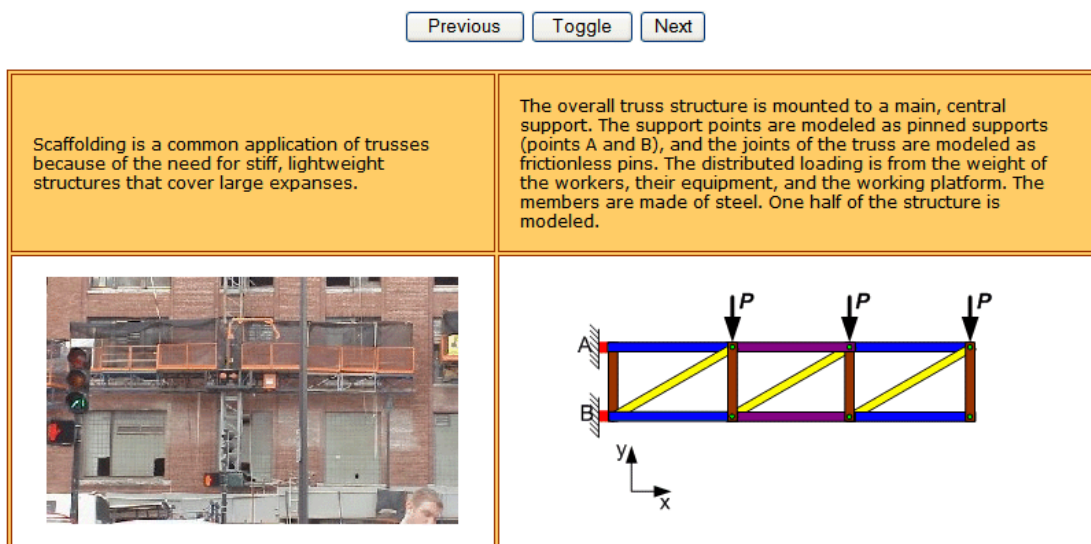


Fig. 5 The same page showing the schematic model of the scaffolding.

e) Online Quizzes

The online quizzes are tools for assessment, both for the students and the faculty. The quiz section actually consists of two quizzes, an in-class quiz and an at-home quiz. The former is administered during class, and the latter is one that the students can use on their own. Both quizzes make use of ASP, which allows them to access a database and produce dynamic content. Following the student engagement model of Mazur⁹, the in-class quiz consists of short conceptual-type questions that the instructor poses to the class. The students use their computers to respond to the questions. The instructor then displays a screen showing the distribution of answers (Fig.6). This allows the instructor to identify common misconceptions and the student to gauge his or her understanding of the material. A tool has also been built that allows the instructor to ask a question “on-the-fly.” This tool enables the instructor to pose a general type of question (true/false, yes/no, A/B/C/D) and to electronically receive responses from the students.

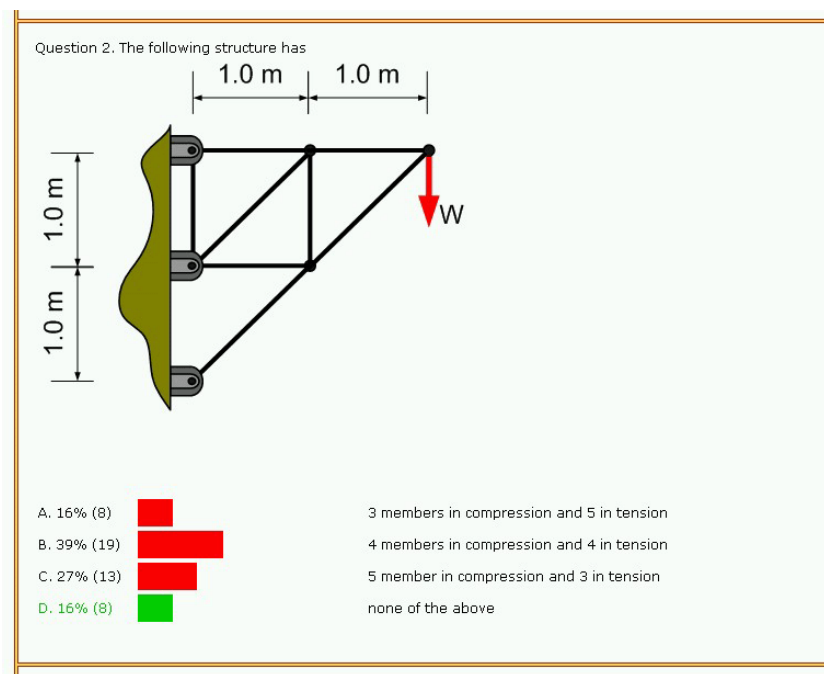


Fig. 6 In-class quiz results (correct answer shown in green, incorrect answers in red).

The at-home quiz randomly draws from a set of approximately 100 questions. The questions are subdivided into 20 textbook-style problems, and 80 short, analytical and conceptual questions. The textbook-style questions are similar to those found in traditional mechanics texts: students are provided with a drawing of a system and other crucial information (e.g. loads and dimensions), and are asked to answer questions about the system. The analytical questions probe knowledge that is based more strongly in the mathematics of the topic (e.g. “What is the bending stiffness of a steel plate 1m wide and 5cm thick?”). The conceptual questions seek to test fundamental knowledge about a topic (e.g. “Which of the following parameters affect the stiffness of a truss element?”). Five questions are asked per instance of the quiz, giving students ample opportunity to test their knowledge of a topic. Submitting the quiz calls another ASP page; this page displays the correct and incorrect answers, giving instant and detailed explanations about the answers to the questions that the student answered incorrectly.

f) Design Problem

A design problem that pertains to the module topic is presented to the students. For most of the students, this is their first exposure to design; this section acts both to introduce the concepts of design and to create another learning opportunity for the current topic. For example, in Beam Bending, the problem asks students to design a diving board given specific weight and dimensional constraints. They are expected to make additional assumptions regarding the problem. They are additionally expected to use the Beam Bending simulation to aid in their design. The fact that there is more than one answer to the problem forces students to examine all aspects of mechanics and to draw from their own experiences. By introducing design at such an early stage of the curriculum, it is hoped that the students will be much more comfortable with - and proficient in - design.

g) Reference Section

The target audience for the reference section is the group of students who have already gained proficiency in the topic. After completing a module, students may at some point in the future need to revisit the subject. This reference section gives those students quick access to key information that presupposes knowledge of the topic. A typical reference section contains a topic overview, material properties, and solutions to common problems. The Friction Reference Section, for example, contains a searchable database of friction coefficients, as well as an overview of the equations of friction.

h) Case Study

The case study is an involved analysis of an actual engineering problem. This section differs from the real world examples in that it introduces a problem from its conception and leads the student through the entire process of engineering analysis. Not only does this offer the student a deeper understanding of the real-world applications of a topic, but it also allows the student to experience the engineering process. The problem presented in the Bending module is that of a snow ski. The case studies are all presented in the same, systematic manner. First, design requirements are gathered based on the basic problem statement. Upon determination of the design parameters, a schematic model is developed. This model is used to determine the underlying mechanics of the problem. Using this information, and the simulation, the design is successively improved. This improvement process gives students a better understanding of the procedures involved in engineering analysis, and the use of the simulation allows students to actively participate in this analysis.

i) Instructor Interface

The instructor is provided with an interface for facilitating the classroom experience. The main goal in creating this interface was to create a quick and intuitive means for the instructor to perform necessary actions. An access-restricted portion of the site allows the instructor to control access to the in-class quizzes, view student feedback, and review at-home quiz questions by module. For the in-class quizzes, the instructor can activate or deactivate the quiz, reset the response database, display quiz results, and store the quiz results to a file for later review (Fig. 7).

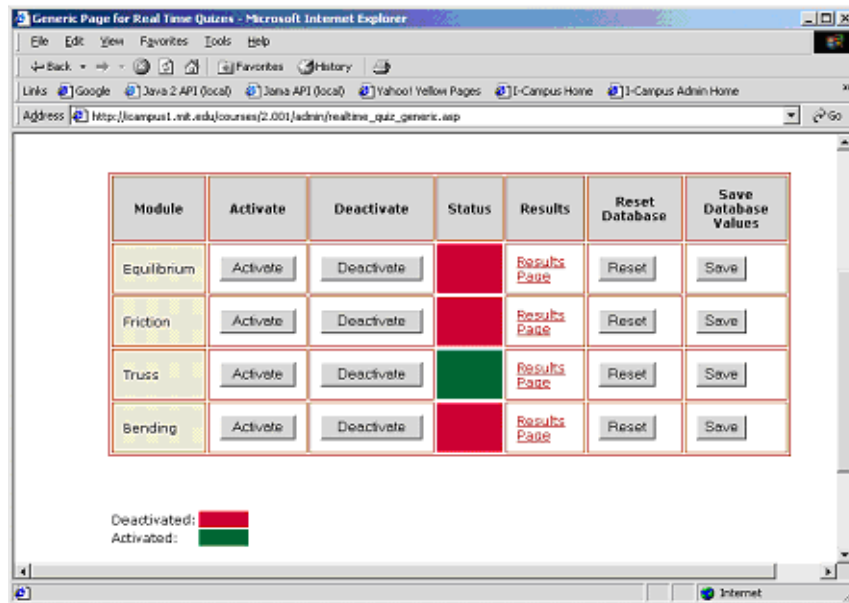


Fig. 7 Instructor interface for in-class quizzes.

III Desktop Experiments

There are currently nine desktop experiments: Free Body Diagram, Static Friction, Capstan Effect, Effective Spring Constants, Truss Structures, Biaxial Loading, Beam Strain, Beam Deflections, and Sandwich Beams. These desktop experiments each correlate to a specific Web module or to a topic within a Web module. Some of the experiments have been used during the last two academic terms, and - based on student and instructor feedback - the desktop experiments provide an excellent means for learning new concepts. Students have remained interested and engaged. By working in teams they have not only learned to work together, but they have also learned to use each other as a part of the learning process.



Fig. 8 A pair of students working together on the Capstan Desktop Experiment.

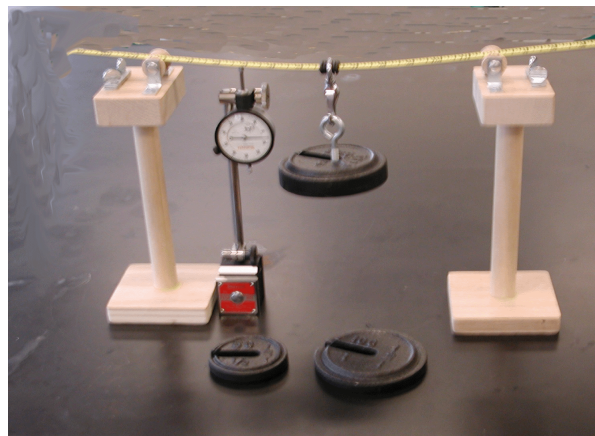


Fig. 9 Beam Deflections Desktop Experiment.

These experiments have been designed to allow students to participate in the process of scientific discovery. Student teams observe physical phenomena through experimentation (Fig.8).

They then analyze the mechanisms and make the connection between the real process and theory. For the Beam Deflections experiment, students measure beam deflections for a specific loading condition and length while varying the beam thickness to determine the relation between beam thickness and beam stiffness (Fig.9). Students represent their results in the form of Cartesian and log plots and pose a mathematical relationship based on these results. They then move on to derive mathematical formulations for these observed relationships.

IV Classroom and Equipment

In addition to developing tools for use within the classroom, the Department of Mechanical Engineering rebuilt the existing classroom during the summer of 2001. The intention in doing so was to align the physical environment of the classroom with the pedagogical objectives of the new course. The old classroom seated almost 100 students and was comprised of rows of small chairs with built-in desks (Fig.10). The new design (Fig.11) features modular tables which can be configured to form tiered rows (lecture-style arrangement) or individual tables that seat students in groups of four (lab-style arrangement). Multiple network drops and power outlets are included at each table; a wireless access point in the rear of the classroom also enables wireless network access. The reduction in seating capacity (60 students) allows students to sit comfortably, to more easily engage in cooperative learning, and to be easily approached by instructors.

The Web-based learning was brought into the classroom by means of a portable computing initiative: each of the students received a laptop computer for the duration of the course. These laptops came complete with all necessary course software. Maintenance and technical support was provided by MIT Information Systems. Campus-wide connectivity was achieved by equipping the laptops with both regular and wireless network cards. In July 2001, MIT Information Systems concluded the installation of 209 wireless access points, covering over 200 locations in 39 buildings¹⁰. This enabled wireless access[‡] to the MITnet from most classroom and library spaces as well as many public spaces across campus.



Fig. 10 The seating style of the old classroom.



Fig. 11 The new Park Room for Innovative Education.

‡. The MIT wireless network currently uses IEEE 802.11b-compliant technology.

V Assessment and Recommendations

Each academic term provides an opportunity to receive feedback which is invaluable in improving the quality of the Web modules. Each term also allows examination of the new teaching paradigm. Realizing that the online portion of the class is a dynamic entity, the Web modules will be kept alive and in a constant state of improvement. This same methodology will be applied to the new teaching methodology - it will be continually refined.

Assessment is an ongoing process and can take many forms¹¹. For this project, focus groups, surveys, student performance, instructor evaluation, and in-class observation are among the most important parts of the assessment procedure. These indicators have been used formatively and will, in the future, be used to develop a summative assessment of the project's success.

During this initiative, the teaching staff has been willing to adopt an unfamiliar mode of teaching. Change is often slow in academia, but the advent of new technology necessitates a radical change in the way engineering classes are taught. It has been noted that there are many dangers to developing courseware without consideration for proper integration into the course¹². In this case, the method of teaching is being changed in addition to the course material. The online material is not simply being appended to the class; the class is being redesigned to incorporate the online portions of the class.

Our success to this point has been dependent on several factors. First, in developing a technology-enabled course, the entire teaching format must be redesigned, if it is to have a reasonable chance at success. Second, the teaching staff must embrace the new tools for teaching. Finally, though a similar program might work with lesser resources, this project has been catalyzed by the portable computing initiative and the construction of the new classroom. Similar endeavors at other programs, though they may vary greatly in their approach, will benefit greatly from these general findings.

VI Acknowledgements

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