Interactive Web-based and Hands-on Engineering Education: A Freshmen Aerospace and Design Course at MIT

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Abstract- *Introduction to Aerospace and Design is a 3 hour per week Freshmen elective course at MIT that culminates in a Lighter-Than-Air (LTA) vehicle design competition, exposing Freshmen to the excitement of aerospace engineering design typically taught in the Junior or Senior years. In addition to the hands-on LTA vehicle design, Introduction to Aerospace and Design also utilizes the new opportunity to interactively present and disseminate curricula over the World Wide Web to motivate and teach students about engineering. Lectures encompass traditional classroom lectures as well as Web-based curricula. During the LTA vehicle design, students work in teams of five to six, design, build, and fly a remote-controlled blimp (typically about 4 meters in length). They race their LTA vehicles in a friendly competition around the gymnasium with the objective of carrying the largest payload around the specified course in a minimum amount of time. The design aspect of the competition gives the students the opportunity to show their creativity and ingenuity in developing an actual flight vehicle. Good note taking and design sketches are promoted by requiring students to prepare electronic design portfolios. All students are required to orally present part of their team's mandatory multimedia Preliminary Design Review (PDR) and Critical Design Review (CDR) before a faculty jury. The students are provided with Web-based PDR and CDR templates to help facilitate concise, well-structured presentations. A project kit, consisting of radio control equipment, batteries, 1-meter diameter weather balloons, electric motors, and construction materials is provided to every team. The students spend a considerable amount of time trying to realize their designs and becoming familiar with the machine shop. By putting the students into random groups, many of the students develop teamwork skills for the very first time. The accomplishment of designing, building, and flying the LTA vehicles is an empowering experience for all students.*

I. Introduction

At MIT, Freshmen take courses from the Institute core requirement list and declare their majors at the end of their first year. They join a specific department in their sophomore year and typically begin to take major-specific courses at that time.

Some MIT Freshmen desire to start their aerospace education in the first year, therefore, we offer electives in the form of Freshmen Seminars [1] and *Introduction to Aerospace and Design*, which is the topic of this paper. Other students may be interested in aerospace engineering but are uncertain whether to select it as their major field of study, while a third group of students, simply desire some exposure to aerospace and design. The MIT Department of Aeronautics and Astronautics first created the Freshman elective *Introduction to Aerospace Engineering* to assist students interested in majoring in the field. To make the course more exciting, the design and construction of a model blimp was integrated into the subject.

Over the past three years (1995–1998) several innovations have been introduced in the course and the name was changed in 1996 to *Introduction to Aerospace and Design* to reflect the real nature of the hands-on design element. The use of the World Wide Web (Web) was made an integral part of the course. Utilizing the Web allows for more flexibility in teaching and learning than conventional approaches [2]. Interactive courseware has been developed for almost every level of engineering education. The most relevant materials are multi-media curricula developed to augment hands-on design courses [3], [4].

The majority of the lectures are presented in a classroom using either the blackboard or a computer connected to the Web curricula via the internet to convey fundamental information on aeronautics, astronautics, and design. Interaction among the students is encouraged and an electronic discussion forum was set up, where students share their ideas, questions and answers about lecture material, homework, or the design project.

The remaining sections detail the Web-based curriculum and Lighter-Than-Air vehicle design project. Information technology and Web-based curriculum are discussed in a positive view looking toward new beneficial educational methods. Three levels of Web-based curriculum are discussed. The LTA vehicle design project is introduced, then the rules and objectives are stated, followed by a description of the LTA design kits handed out to student teams, descriptions of the required electronic design portfolios, PDR, and CDR, and finally, the LTA vehicles trials and race day are discussed.

II. New Educational Methods

A. Introduction

We wanted to explore the flexibility offered by the World Wide Web for educational purposes. One key advantage is the ability to constantly update documents and disseminate information at any time. For instance, the Web-based course syllabus is a fluid document that is updated or changed whenever needed and thus is far more helpful for the students than one printed on paper, handed out on the first day of classes, and quickly outdated. Web pages allow the instructor to use color text, images, animations, short video clips, etc. freely in the presentation of lecture material. It should be possible to assess different styles of student learning through information technology and we are creating our material based on previous successful implementations [2], [5], [6]. There are no exams or quizzes given in the course.

B. Lectures

Introduction to Aerospace and Design is taught in the spring semester (14 weeks) and consists of two 90-minute lectures per week. The majority of the lectures were held in a traditional classroom in which the material was presented either on the blackboard or from a computer connected to the Web-based curricula. In addition, some lecture material was illustrated with the viewing of short videos. The students were asked to come prepared to the lecture by reading through the appropriate material on the course Web site beforehand. It was observed that student note-taking was similar to that in conventional classes.

Lectures cover three main areas: aeronautics, astronautics, and design. The aeronautics lectures are given the first month of the course and include: a historical perspective, lift and drag, aircraft performance, weight and structural considerations, propulsion, human-powered aircraft, and stability and control. Intermingled with the aeronautics lectures are the design lectures including an introduction, the design process, and a drawing lecture. The design lectures are followed up with a week long exercise in hands-on design of a two-dimensional house using the Delta Design game [7], a team exercise developed by MIT Professor Louis Bucciarelli. Students are assigned one of four roles: a thermodynamicist, a structural engineer, an architect, or the project manger. Students learn that the most efficient teamwork often yields an optimal design. Teamwork and good communication skills are emphasized and taught throughout the course [8]. Once the LTA vehicle design project commences, four lecture slots are designated as design days, and the LTA vehicle race trials and race day account for an additional two mornings. The astronautics lectures take place in the last month of the course and are mostly for information purposes, and tend not to be essential to the LTA vehicle design project. Over 80 percent of the students raise their hands on the first day of class when asked the question, "How many of you want to be astronauts?" The astronautics lectures on the space environment, orbital mechanics, satellites, space suits, and space flight experiments give an overview of some of the current activities in space. This lecture material often gets enthusiastic reviews from the future astronaut crowd.

For about 15 percent of the lectures in *Introduction to Aerospace and Design*, computer interaction is desired for the professor as well as the students, and these lectures are held in an electronic classroom. This room provides every student with an individual workstation and monitor as well as a large projection screen that displays the instructor's workstation. It was found that the best utilization of the computer classroom was to present the history lecture based on mostly pictorial information and the human powered flight aircraft lecture that included photographs and models of aircraft. This lecture was presented in a slide format on the computer so that students could go forward or backward at their own pace. An experimental group of five student volunteers used the electronic classroom to play the Delta Design game electronically, rather than on the game board. Their comments on the experience were positive, but the vast majority of the students chose to play the design game on the conventional playing board. The computer classroom is also used for Web tutorials. A different electronic classroom with one workstation and split screens is used for student PDR and CDR presentations.

Note-taking for students in the electronic classrooms proves to be difficult. Since most of the desk space is taken up by the computer and the area for the mouse, writing on paper was somewhat cumbersome. Current Web browsers do not offer a solution for taking notes by hand in addition to interacting with the computer. Simultaneous use of a text editor or word processor by the students to take notes was not observed.

The obvious danger in having students sit in front of a computer is that students might not follow the lecture, but instead read/write e-mail or surf the Web. The experience in this regard was very positive with students' attention focused on the computer lecture. One helpful factor may be that access to workstations at MIT is readily available and that the hardware/software in the electronic classroom is identical to that provided to all students campus-wide and thus, did not represent a distraction.

C. Various Backgrounds

The students enrolled in the course possess a wide range of backgrounds. While some students will certainly select a career in aerospace and have already acquired extensive relevant knowledge before entering MIT, others are completely unfamiliar with basic aerospace concepts or ideas. Similarly, the students have various levels of pre-college preparation. Since the course is taught in the spring term, the Freshmen are assumed to have completed their coursework in single-variable calculus and the physics of mechanics.

The material presented in class is aimed at the average to above average student. As a consequence, a few students struggle and need additional emphasis on fundamentals, while others are dissatisfied with the lack of details and seek material that is more challenging and beyond the scope of the course. The use of the Web has made it possible to address the needs of both groups of students. The course Web site offers a link to the "Aerospace Fundamentals" curriculum that we have developed, which reviews the fundamentals with fewer equations and more diagrams. Originally developed for high-school juniors and seniors, the Aerospace Fundamentals allows those freshmen that need help a very thorough and basic understanding that they can master at their own pace and without any embarrassment. The fundamentals of flight, aircraft principles, rocket principles, spacecraft principles, and humans in space comprise the five areas that are accessible in this fundamentals section. Each of the five topics starts with a pictorial history section, then the principles are discussed, followed by class discussion questions and possible activities and research questions, and finally, sample problems are given. The Aerospace Fundamentals curriculum is well-suited for self-study or could be used as self-contained teaching modules for a high school class.

Those students who desire further knowledge beyond that presented in lecture are directed to Web sites of the upper-level courses in the MIT Department of Aeronautics and Astronautics, the MIT on-line library system, and outstanding external aerospace Web sites. In a conventional course with a textbook, it is quite difficult and time-consuming for accelerated students to learn independently. Since their time is so-limited through regular curricular and extra-curricular activities, the advanced material has to be easily accessible. Following prescribed Web links and reading material on-line makes independent study easier than ever before, and hopefully, very rewarding.

The three levels of Web-based curriculum are denoted: aerospace fundamentals, lecture material, and advanced material. In a forthcoming textbook and CD-ROM [9] based on this Freshmen course we have designed the CD-ROM to be interactive and reconfigurable to cover the three levels. For example, one student might listen to the Stability and Control lecture in class and then choose to review the fundamentals of flight and aircraft principles to make sure he/she understands the essential concepts. While another student after listening to the same lecture would be directed to an upper level aerodynamics course via the advanced material link.

While most students have experience with the World Wide Web, only half entered the course in the Spring of 1998 with knowledge of HTML (Hypertext Markup Language) or the creation of multi-media Web pages in general. Hence, optional tutorials on composing Web pages relevant to their upcoming design portfolio, PDR, and CDR assignments were provided. At the end of the course, most students felt that the use of the Web represented an additional workload to them, but all were happy they had this experience so early in their career at MIT.

Students are also encouraged to access the provided links leading to historical references and entertaining stories [10] in the Web site. These historical references are provided to help students further understand the historical significance and engineering context of lecture material.

III. Hands-on Lighter-Than-Air Vehicle Design

A. Introduction

This section emphasizes a critical component of engineering education, design. Students are immersed in the hands-on, lighter-than-air (LTA) vehicle design project that culminates in a race competition at the end of the semester. It exposes Freshmen to the excitement of aerospace engineering design typically taught in the Junior or Senior years. The students work in teams of five to six, and design, build, and fly a remote-controlled blimp (typically about 4 m in length). By randomizing the design teams, many of the students develop teamwork skills for the very first time. The design aspect of the competition gives the students the opportunity to show their creativity and ingenuity in developing a flight vehicle. The goal is to achieve an active learning environment for acquiring a conceptual framework as well as problem-solving skills. The connections between theory and practice become real in the LTA vehicle design. The Freshmen are empowered by the challenge, and it is the instructor's job to assure that all teams successfully accomplish the design project. This experience is exactly what Freshmen who are trying to decide whether to major in engineering need. Design is an integral part of the practice of engineering [11], [12] and we believe it should be an integral part of students' education during their entire undergraduate career.

Design is introduced to the students formally through lectures on "What is Design?" and "The Design Process," which are followed by the previously mentioned design exercise, the Delta Design game that we find very useful in establishing teamwork and communication skills. Then students receive an introductory drawing lecture, and finally embark upon the LTA vehicle design project, which counts for 50 percent of their grade. The LTA vehicle project starts the fifth week of the course with a discussion of the rules and objectives and a description of the LTA vehicle kit. Students are required to keep individual electronic design portfolios and all student teams give oral presentations during the required preliminary design review (PDR) and critical design review (CDR). After the CDR, the LTA vehicles are built and then flown during the race trials and final race competition. A friendly competition is emphasized and success means every vehicle flies. All lecture material can be found at the course Web site http://web.mit.edu/16.00/.

B. Rules and Objectives

The LTA vehicle design objectives, race course, constraints, design kit, data on components, milestones, and logistics are briefly described. The objective of the design contest is to design and build a radio-controlled (RC) lighter-than-air vehicle that flies, is controllable, and makes it around the basketball court. Secondary to achieving flight, are the metrics of reliability, speed, minimum structural weight (or maximum payload carried), and aesthetics. Winners are judged on the following criteria: reliability is the percent of completed to attempted flights around the basketball court; speed is clocked from the starting line, down the sideline, across the baseline, down the opposite sideline, across the baseline back to the starting line; the minimum structural weight is measured by placing the entire LTA vehicle on a scale at the beginning of race day, as well as measuring the maximum payload mass the LTA vehicle can carry up to a total vehicle gross mass of 1.5 kg; and LTA vehicle aesthetics are judged by a faculty jury. The race course is shown in Figure 1 with the start and finish at the bottom left corner, the four stationary balloons at the corners of the basketball court must to be flown around in a clockwise pattern. One of the most difficult aspects of the LTA vehicle race is negotiating the three required turns.

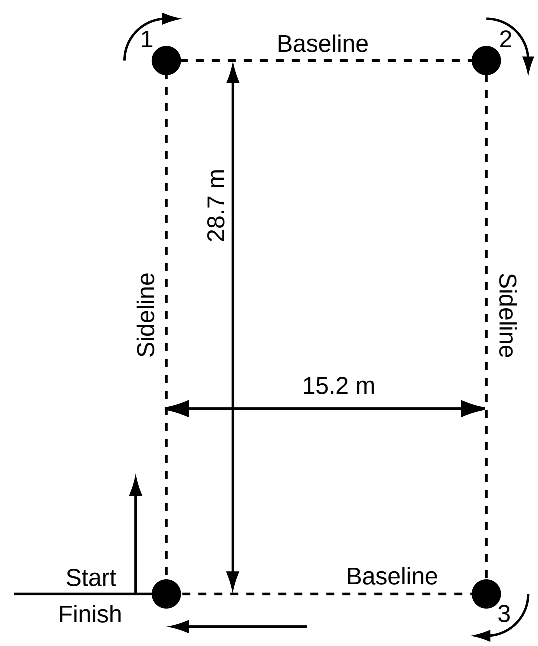

Fig. 1: Lighter-Than-Air Vehicle Race Course.

C. LTA Vehicle Design Kits

All teams are provided with a LTA vehicle design kits that include the following:

- Building materials and supplies (balsa wood (available in sheets and strips), aluminum, and epoxy)
- Weather balloons (up to 5 balloons)
- Helium
- 4-channel Futaba radio control system that includes a receiver, three servos, and AA batteries
- Standard issue motors, large or small
- Standard issue propellers (2.7 cm diameter, 3 degrees of pitch)

Data are provided on the LTA vehicle components to assist in the analysis required for the PDR and CDR. Balsa wood is assumed to have a density of 160 kg/m^3. The 70 g weather balloons are 1 m in diameter and can be overfilled. The density of helium is 0.174 kg/m^3. The Futaba 4-channel RC system has a hand-held AM transmitter and battery, a 27 g receiver and battery (0.094 kg, 4.8 V, 0.500 A) that is used to run servos but can also be used to run motors. The servos are 0.043 kg each. Additional batteries are 50 g each (1.25 V, 1.2 A).

Each team has the choice of using large or small motors or both (to be finalized by the CDR). The Pittman Motors (0.21 kg) are larger than the Edmund Scientific motors (0.0897 kg). The attached propellers are an additional 0.0052 kg mass; the total RC mass is 0.2906 kg; and the battery energy density is approximately 30 W/kg. Motors work approximately 2/3'rds as well in reverse due to propeller inefficiencies. The Pittman motors provide 3 N of thrust while operating at 16 V, drawing a current of 4.45 A, and requiring 80 W of power, while the Edmund Scientific motors provide 0.36 N of thrust for operating specifications of 15 V, 2 A, and 30 W. Complete component performance tables are provided to the students.

All students must attend a machine shop safety lecture and additional machine shop technique is acquired through a homework assignment that requires students to view nine Web-based machine shop tutorials written by MIT's Mechanical Engineering Department. These tutorials cover materials and machining technique, which is more than what is required for the balsa wood LTA vehicles. Using electronic tutorials in this way serves to stimulate the students who have a quest to understand the machine shop in detail and also provides essential information that can not be covered in lecture for lack of time, and is more suited to self-study and tutorial format. The students are graded on this homework assignment by their peers through a question-and-answer session with the understanding that all team members must have the basic understanding of how to work in the machine shop.

D. Electronic Design Portfolios

Students are required to turn in an electronic design portfolio at the end of the course. At the beginning of the term they are informed of the requirement and are encouraged to take good notes as well as to sketch all the concepts that come to their minds throughout the term. The assignment counts for 15 percent of their grade. Computers, software, scanners, and printers are available to students. In addition, a Web-based HTML electronic design portfolio template is provided to enable students to get their materials on the Web by simply plugging in their own graphics, rather than writing computer code. The goal of the portfolio assignment is to actively engage students in the design process and to allow them to watch it take shape throughout the semester via their individual efforts and team designs. The seven required sections of the portfolio are listed below:

1. Notes from lectures, homework preparation, library searches
2. Sketches from past homework assignments, LTA brainstorming, daydreaming, etc.
3. Concepts are similar to sketches, but they might include the synthesis of more than 1 sketch and/or include holistic systems thinking
4. Drawings of your LTA components and design configurations
5. Critical Analysis of your LTA design (i.e., preliminary calculations, equations, and analysis)
6. LTA Prototype Design
7. LTA Race Vehicle Design

An unexpected benefit of the design portfolio assignment has been to provide freshmen with a comprehensive synopsis and catalog of their engineering design work that is very attractive to potential summer employers. Typically, freshmen have difficulty finding engineering summer jobs in part because of lack of experience and minimal résumé qualifications.þThese impressive portfolios are sufficient to convince employers to take a chance on a Freshman, and they also serve to build the confidence of the students who see their comprehensive semester efforts before them. Students learn proper referencing technique as they are required to explicitly state what is their original work and what their specific contributions are to the overall team design. The portfolios are due with three weeks remaining in the term, and students are allowed to update and enhance their work until the last day of the semester in hopes of improving their grade.

E. LTA Vehicle Design Reviews

All students are required to orally present part of their team's mandatory multimedia Preliminary Design Review (PDR) or Critical Design Review (CDR) before a faculty jury. Similar to the electronic design portfolios, the students are provided with Web-based PDR and CDR HTML templates and a tutorial to focus on the presentations rather than computer programming. The design reviews teach the students how to give concise, well-structured presentations. The goal of the reviews is to introduce them to real-world engineering requirements and to further emphasize the design process rather than only a finished product. The required slides and instructions for the PDR and CDR are listed below:

1. Title slide—Introduction including Team Name and Team Members.
2. Agenda—An overview of your presentation.
3. Design schematic—showing approximate relative sizes of your balloons, propulsion system and attitude control system.
4. The details of your design including:
   - Helium Volume
   - Vehicle Mass Estimates
   - Estimates of Vehicle Drag
   - Estimates o Vehicle Thrust
   - Number and Placement of Motors and Propeller
   - Number, Size, and Placement of Batteries
   - Method of Attitude Control and Maneuvering
   - Expected Vehicle Velocity and Duration of Flight
5. Dimensions and layout (similar to the schematic, but with dimensions and detail).
6. Requests for any special materials including quantity and costs.
7. The schedule of vehicle construction and testing leading up to the weigh-in and race.

The explicit goal of the PDR is to present the first cut of the LTA vehicle designs and students are given the following guidance:

> *Remember, you are engineers. If you don't have firm numbers of every component make a reasonable estimate based on what you have learned in lecture or what you look up.*

Prototypes are encouraged throughout the PDR and CDR stages, and experience has shown that those teams with prototypes, produce better vehicles and are more successful in the race.

The explicit goal of the CDR is stated as presenting your team's final design. The main requirement change between the PDR and CDR is that scale drawings are required for the CDR, and the students should enumerate how different design options were eliminated and the final design chosen. Students are also given a cautionary recommendation to bring overhead transparencies to their CDR as a backup for the Web presentations. A benefit of the Web presentations is that incremental changes can be made to the PDR and students can use any of their design portfolio materials, saving them time, and resulting in professional CDR presentations with very little additional presentation time expended. Student designs are discussed and shown below. One team prepared an elaborate animation for their PDR that received extensive audience applause, but their fancy computer animation did not suffice for the required analysis and knowledge of fundamentals. The team received a low PDR mark and hopefully learned a bit about time management, the importance of completing the entire assignment, and the complexity of a sound design. Figure 2 shows a student's LTA vehicle drawing.

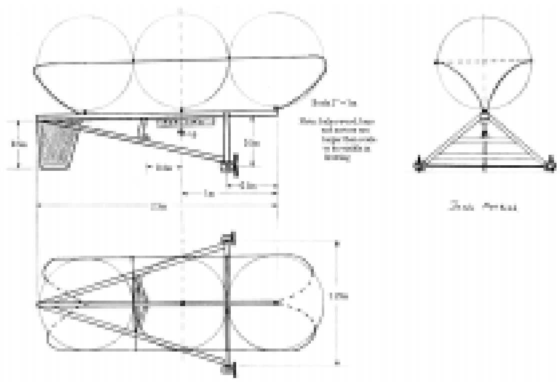

Fig. 2: LTA vehicle scale drawing for the critical design review (CDR) (Courtesy of J. Markish).

F. LTA vehicle trials and race competition

They LTA vehicle trials and race day offer a friendly competition with teams flying their vehicles (one at a time, due to their large size) around the gymnasium. There is a week between the trials and actual race day to allow for LTA vehicle re-designs. The students learn invaluable lessons during the trials, such as, how much lift 4 helium-filled 1 m diameter weather balloons actually provide, what control really means as they try to negotiate the first corner of the course, and stability has a new found meaning when balloons in series start to oscillate. Teams endure structural failures, batteries running out, and propellers threaded incorrectly to learn perhaps their most important systems design lesson—that any flying machine is a complex system.

Below is a student's summary of the race trials:

> *At the preliminary flight trials our craft did quite well. The batteries ran low just as we completed the circuit. At the onset, the speed made control more difficult but it was just something to get used to. As the craft slowed, control became more sluggish but stability was greater. The inverted-V stabilizers we had attached near the rear seemed to null the effect of the rear motor to give yaw control so we have tentatively decided to remove them. We figure that the inherent stability of our craft will not be greatly effected because its going so*

slow. Our yaw control needs more command so it seems logical. However, whether a vertical stabilizer would help is yet to be determined. It seemed like the craft "porpoised" a bit and removing the stabilizers would seem to make this even worse. We may make stabilizers that are removable so that we can fly without them and if needed, add them at the race.

The race day offers the students their moment of glory with peers, faculty, and even family in the stands. As previously mentioned, success in *Introduction to Aerospace and Design* from the Instructor's point of view is to have all the LTA vehicle teams successfully fly around the course. In doing so, we cheer, applaud, and recognize the fine design achievements of our students. Every year there are new creative designs and the numerous hours of time spent in the machine shop are evident. Students are allowed to see previous years' LTA vehicles on video and are encouraged to improve upon them and also to critique the past designs.

G. Summary

Through the theoretical lecture material and the LTA project, the first-year students receive a preview of what lies ahead in the next three years of their education, a preparation for it, as well as a rudimentary systems perspective, so important in aerospace engineering. The Web-based curriculum offers flexibility and is designed to accommodate various student learning modes. The Freshmen have a fun, hands-on engineering design experience during their first year of college that excites them for a career in engineering. Most importantly, for the past two years we have ensured that all teams succeed in flying a LTA vehicle by race day, an empowering experience for the Freshmen students.

The time commitment and dedication to develop and offer this type of interactive, design course are not trivial. In the spring term of 1997, seven individuals were involved in Introduction to Aerospace Engineering and Design. Typically, a Professor, Technical Instructor, and possibly a student Teaching Assistant would be required to offer the course, but during the development of the Web-based curriculum two graduate students and three undergraduate students were hired as teaching assistants or hourly workers to assist with course implementation. The work opportunity is beneficial to students and enhances their knowledge of course material by being actively involved in the presentation and delivery of the curriculum.

Introduction to Aerospace and Design investigates the new opportunities offered by information technology for education and provides students a real engineering experience through the hands-on, lighter-than-air vehicle design project.

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V. ACKNOWLEDGMENTS

The author would like to acknowledge support provided by the NSF's ECSEL program, the MIT Class of '51 and '55 fund, the Department of Aeronautics and Astronautics, and the MIT Dean of Engineering. Thanks to Richard Perdichizzi and Don Weiner for there endless technical support for the LTA vehicle project. Thanks to the following MIT faculty members who have served as faculty jurors: Earll Murman, Steve Hall, and John Dugungi. The students have made enormous contributions to this effort and I would like to thank Amir R. Amir, Esther Dutton, Qun Liang, Renata Pomponi, Tyra Rivkin, Elizabeth Walker, and all 16.00 students from 1995-98.