Integrated Teaching of Experimental and Communication Skills to Undergraduate Aerospace Engineering Students

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1. INTRODUCTION

The ability to communicate clearly and precisely is integral to the ability to think critically and creatively. Because of the interdependence of clear thought and clear expression, there are significant benefits associated with integrating the teaching of communications and other professional skills with advanced, small-group laboratory research. This paper describes the coupling of an undergraduate *Experimental Projects Lab* with a *Communications Practicum.* The two subjects are taught jointly by faculty members from the MIT Aeronautics and Astronautics Department and the MIT Program in Writing and Humanistic Studies. The pairing of the experimental projects course and the practicum provides an environment for teaching communications skills in which the students are interested in the subject matter and motivated to learn. In addition, a variety of modern information technologies are applied to augment the effectiveness of the practicum. Several pedagogical themes are interwoven into the two courses including hands-on learning, cooperative education, writing-to-learn, and mentoring. The courses jointly serve to educate students in a variety of aspects of professional engineering practice including solving open-ended problems, integration of disciplinary coursework, project development and planning, oral and written communication, peer review, and teamwork.

The *Experimental Projects Lab is* similar to an undergraduate thesis in scope. Each team of two students chooses an original research project and is guided by a faculty advisor over the span of two semesters. The students participate in all aspects of experimental research including project definition, proposing, design of the experiment, construction of apparatus, completion of the experiment, and analysis and reporting of results. The *Communications Practicum* provides focused instruction in both written and oral communication skills. The practicum syllabus is closely coupled to the projects lab. Strong motivation for the students to learn communications skills is provided since only a small fraction of the grade in the projects lab is determined by the faculty advisors who work with each student team. The majority of the grade is awarded by the course staff whose main insight into the research project is through a variety of written and oral assignments. Practicum instruction is conducted in a specially designed electronic seminar room which allows online drafting, annotation, and peer review of documents, as well as video-taping and peer review of oral presentations, prior to their being presented for credit in the experimental projects course.

This paper describes the unique features of this approach to undergraduate engineering education, and represents a progress report following a three-year experimental implementation of the new course model. The *Experimental Projects Lab* and the *Communications Practicum are* described in more detail in Sections 2 and 3, respectively. The objectives of the two courses, overviews of the course formats, and examples of course materials are included. In Section 4 the modern information technologies which are used in the practicum are reviewed. An assessment of the effectiveness of the practicum based on student course evaluation responses is presented in Section 5. Section 6 contains a summary and conclusions.

2. OVERVIEW OF THE EXPERIMENTAL PROJECTS LABORATORY

2.1 Motivation

The motivations for providing a structured undergraduate research experience are multifold. The processes of conception, design, fabrication, experimentation, and discovery are central to both engineering and research. Therefore, research projects provide excellent vehicles for training students in engineering practice. Such an experience can serve as a vehicle for unifying and applying knowledge gained from disciplinary coursework. Further, much deeper understanding and appreciation of physical phenomena can be developed when 'hands-on' learning is combined in an integral manner with more traditional classroom instruction. Experimental projects also offer exposure to the 'implicit curriculum', that is, things students are expected to learn which do not appear explicitly on any course syllabus (e.g. ethics, group dynamics, Murphy's Law). In addition, a structured research experience can be an important opportunity for one-on-one student collaboration with a faculty member over an extended period of time in which the faculty member can serve as a role model and a mentor.

While it is true that communications skills area critical aspect of engineering practice, it is often the case that training in communications is viewed as a bitter pill by undergraduate engineering students. The students feel that "... it's not what I came here to learn," or they fail to recognize the importance of communications skills for career advancement. More importantly, the students are often unaware of the interdependence of thinking and expression, and the positive influence that having to communicate can have on the progression towards a technical goal. As noted by Hoffmann[2], "The writing of a research paper is in no way an activity divorced from the process of discovery itself. I have inklings of ideas, half-baked stories, a hint that an observation is relevant. But almost never do I get a satisfactory explanation until I have to, which is when I write a paper." These ideas are echoed by Dorman and Pruet[3] and Mavher[4] who stress that writing is a way to think. Dorman and Pruet also note that "Ultimately, motivating students to write is more important than teaching them how. The more clearly students perceive future demands, the better they prepare themselves to satisfy them." Over one-third of an average engineer's day at work maybe spent writing[5]. The pairing of the experimental projects course and the practicum was intended to provide an environment for teaching communications skills in which the students are interested in the subject matter and motivated to learn.

2.2 Experimental Projects Lab Objectives

The *Experimental Projects Lab is* a required part of the Aeronautics and Astronautics Department undergraduate curriculum. It serves as one of two capstone courses (the other course is a senior-level systems design project) and is taken by students in their junior or senior year. The primary objective of the course is to provide exposure to the methods, processes, and techniques involved in conceiving and conducting an experimental research project. Each group of two students chooses an original research project and over the period of two semesters conducts research under the guidance of a faculty advisor.

The distinction between a research experience and a laboratory experience is important. In a laboratory course the experiments are prepared in advanced, are designed to have specific solutions, and have been solved by other students in other years. In a research-oriented course the problems are spawned directly from sponsored research activities in the department or from original ideas proposed by the students themselves. This brings to bear the full weight of difficulties associated with solving open-ended problems under conditions of uncertainty. This often results in multiple confrontations with Murphy's Law: *Anything that can go wrong, will go wrong – and at the worst possible moment.* The necessity for accurate record keeping, and contingencies for experimental planning, budgeting, and scheduling is made clear, whereas the utility of these procedures often rings hollow in prepared laboratory experiments. In these ways, a research project replicates many of the important aspects of an engineering project. One-on-one collaboration with a faculty member over an extended period of time is necessary to make this a tenable situation for undergraduate education. The guidance is important to ensure that the project stays within the two-semester time frame and the desired number of credit hours. Often a continual battle is waged to reduce the scope of projects designed by overly-ambitious students.

The long term, one-on-one collaboration with a faculty member fosters a mentor-mentee relationship that benefits the student in many ways. The advisor is a resource for informal advice about a variety topics related to the student's professional development. In addition, the students see first-hand how the advisor reasons and deals with problems and so improve their own skills through a form of apprenticeship. The faculty advisors also benefit from participating in the course. They use the course as a means to perform preliminary investigations to speculate on new ideas, or to augment existing sponsored research efforts.

Further, as a research team, the students learn from each other. Studies of cooperative learning have highlighted several benefits of this educational structure including more effective processing of information, increased student interaction, improved retention of material, and improved overall performance. Moreover, cooperative learning is an effective way of preparing students for industrial settings where team work is stressed. The course grading algorithm is such that approximately one-third of the grade is based on group performance, providing strong motivation for the students to work to improve team performance.

Another objective of the course is to provide the students with "hands-on" experience in dealing with materials, instruments and other apparatus which constitute the experimental tools in an area of aeronautical and astronautical engineering which is of interest to them. The tools employed vary widely depending on the specific research project. The students often use existing sponsored research facilities including wind-tunnels, water-tunnels, vacuum chambers, material testing machines, gas turbine engines, flight simulators, and flight test aircraft. In addition, students are usually required to design and construct some portion of the experimental apparatus themselves. In the past the students have constructed a variety of specialized apparatus, sensing instruments, wind-tunnel models, electronic circuits, and software algorithms.

The course is also designed to provide a forum for the students to develop the communication skills necessary to relate their technical contributions to other professionals in their field. This is accomplished by requiring the students to follow the steps that must be taken to initiate, execute, and complete an experimental research program in industrial, academic, or government settings. Among the steps are the development of proposals, participation in design reviews, documentation of progress and presentation of results. It is this area of the course that we sought to enhance by coupling the course with the *Communications Practicum.* Indeed, we found the coupling to be mutually beneficial. That is, both the students' ability to be an effective researchers, and their ability to express themselves were improved.

2.3 Laboratory Course Format

Substantial involvement by both students and faculty members is required over an extended period of time. The students work in teams of two with a faculty advisor. The advisor is responsible for the guiding the students through the design and execution of the project and interpretation of results. Weekly meetings are most often the mechanism for this interaction. The course staff includes two faculty members and several professional laboratory personnel. The laboratory personnel work with the students on specific techniques and procedures involved with the fabrication of facilities and execution of the experiments. The course faculty are responsible for the organization of the course, course administration, classroom lectures, general advising, coaching, critiquing, and for determining the students grades based in large part on written and oral presentations of the work.

The laboratory course is divided into two semesters. The first semester requires approximately six hours per week and the students conceive, propose, and plan a research program. During the first week of class, the students choose a research topic from a list of prepared abstracts submitted by the faculty members. Students are also encouraged to pursue their own ideas for a project and to discuss these with potential faculty advisors. Approximately twenty percent of the projects are initiated by the students; the remainder originate from the faculty. A list of project titles from Spring Semester 1995 is shown in Figure 1. The topics encompass many of the research interests of the department's faculty and students.

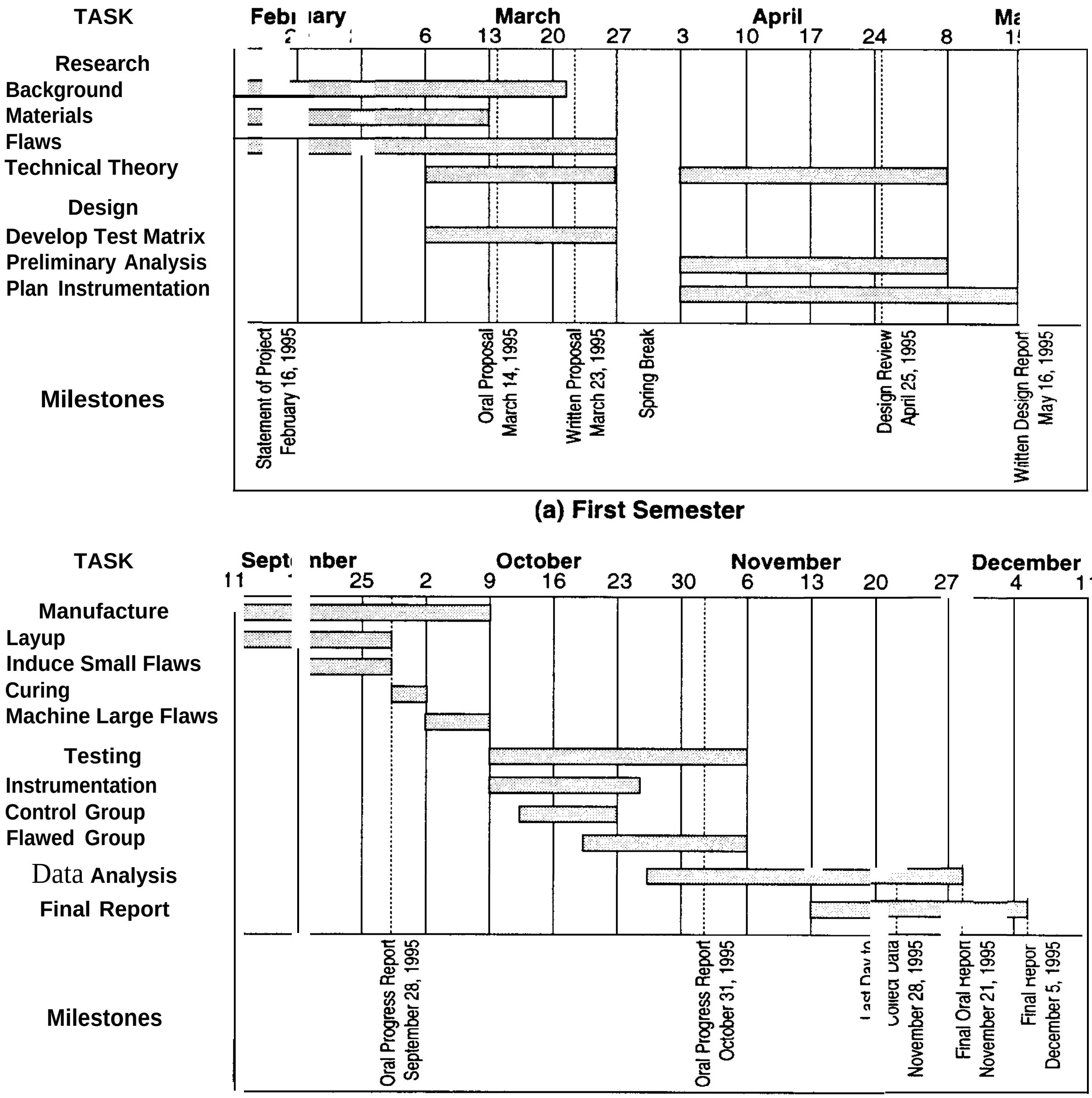
Low-Drag Surfaces for Satellites
Effect of Massive Roughness on Airfoil Lift
Lift and Drag Effects of Alternate Auxiliary Fuel Tank Configurations on an F-16
Winglets at Take-o#and Landing
Analyzing the Vibration of a Tennis Racket
Piezoelectric Actuator Control of a Helicopter Rotor
Acceleration Perception in Humans
Advanced Air Traffic Situation Control System
Self-Regulated Evaporative Cooling of Rotating Turbine Blades
Improving Airfoil Performance Through Active Vortex Control
Effects of Thermal Cycling on Composite Material Strength
A Communications System for Diver Support
Spacelab Visual Environment Simulator Model
Intelligent Battery Monitoring and Management System
Ski Tower Padding Safety Analysis

Figure 1: Example project titles from Spring Semester 1995.

During the first semester the class meets for an hour twice a week. Half of the meetings are set aside for formal classroom instruction on research practice including ethics, the scientific process, keeping lab notebooks, scheduling, and budgeting (3 hours), design of experiments (2 hours), instrumentation (1 hour), engineering drawings (1 hour), error analysis (4 hours), and treatment of data (2 hours). In addition, the students receive a safety lecture (2 hours) and instruction in machine shop skills (4 hours, practical). The remaining class hours are set aside for presentation of oral talks and informal consultations on written work. The text used for the course is *Mechanical Measurements* by Beckwith, Marangoni, and Lienhard[7].

The sample student project schedule shown in Figure 2a illustrates the typical tasks and milestones associated with the first semester of the course. The students are graded on a two page statement of project, an oral presentation of the proposal, a written proposal, an oral presentation of the experimental design report, the written experimental design report, and the content of their laboratory notebook (three periodic checks are made). The goal of first semester is for the students to have all aspects of the research designed and planned. This includes creating mechanical drawings for fabrication of apparatus, assembly drawings and circuit diagrams, ordering materials, submitting safety forms, and formulating an experimental test plan.

The second semester of the lab course is 12 hours per week and involves constructing the apparatus, conducting the experiment, analyzing the data, and reporting on the results. A sample student project schedule for the second semester is shown in Figure 2b. There are no formal class room lectures. The students are graded



(a) First Semester

(b) Second Semester

Figure 2: Sample student schedules for the *Experimental Projects Lab*[8].

on two oral progress reports, a final oral presentation, a written final report, and the content of their laboratory notebook (three periodic checks are made).

The research conducted by the students in the *Experimental Projects Lab is* of very high caliber and sometimes results in departmental or school-wide awards, recognition in American Institute of Aeronautics and Astronautics student paper competitions, archival journal papers co-authored with faculty members, and patents. The course has perennially been one of the more popular subjects offered by the Aeronautics and Astronautics Department.

2.4 <u>Coupling Between the Projects Lab and the Communications Practicum</u>

It is during the first semester of the *Experimental Projects Lab* that the students have the option of taking the *Communications Practicum.* Over the last three years, approximately eighty percent of the students have elected this option. Schedule conflict was the most frequently cited reason for not co-registering the lab and the practicum. The coupling between the projects lab and the practicum is designed into the syllabi of the two courses; for example, drafting and peer review exercises are scheduled in the practicum before the assignments are due for the projects lab. The coupling between the two courses is enhanced through inclusion of the practicum instructor in the weekly meetings of the laboratory course staff members.

The majority of the student's grade in the projects lab is determined by the course faculty whose knowledge of the student's research performance is based primarily on what is communicated by the student in formal written and oral presentations. The faculty advisor and laboratory staff play only a limited role in assessing the students performance (less than 30% of the course grade). Therefore, effective communication of ideas by the student is essential, and the grading structure provides a direct motivation for the students to improve their communication skills.

3. OVERVIEW OF THE COMMUNICATIONS PRACTICUM

3.1 Motivation

Part of the process of educating our students within the full context of professional engineering is training in communication skills, both written and oral. Students must be able to communicate their ideas to others within their own working group, to members of their professional societies, and to the larger world of non-professionals whose lives are impacted by their work. In addition, the ability to communicate clearly and precisely is integral to the ability to think critically and creatively, as an individual or part of a team[3,4]. It is difficult, if not impossible, to span the increasingly multi-disciplinary character of engineering science without good communications skills.

MIT has always sought to embed communication and language in the context of engineering science. Over thirty years ago, Humanities faculty in collaboration with the MIT School of Engineering established the Technical Writing Cooperative in which communications instructors visited engineering classes to present lectures on technical writing and oral communication. From this collaboration came the development of separate technical writing classes offering engineering students training in the general principles of technical communication.

Yet both of these structures present pedagogical problems. The technical writing cooperative offers only limited instruction and minimal feedback from the communications instructor. The traditional technical writing class offers more in-depth instruction on the principles of good writing and speaking, as well as greater feedback, yet it does so out of context, with the presumption that lessons in communication will carry over to a student's engineering classes. Sadly, this is not always the case. MIT faculty in both the School of Engineering and the School of Humanities and Social Science (SHSS), while pleased that both these structures exist to serve our students, nevertheless sought a more flexible and tailorable instructional paradigm for educating our students in the full context in which engineering is practiced.

3.2 Practicum Objectives

During the 1993-94 academic year SHSS in collaboration with the MIT School of Engineering offered a new Writing Initiative to meet this need. The Initiative is designed to offer communications practica which are attached to existing engineering subjects. The practicum class gives a small group of students (enrollment is limited to fifteen) the chance to work intensively on written and oral assignments directly related to the work each student is doing in the engineering subject.

The *Experimental Projects Lab* was one of two engineering courses which were initially chosen as experiments for implementation of the Writing Initiative. Because the pairing of the projects lab with a communications practicum was particularly successful, it has since served as a model for pairings of communications practica with a variety of engineering and science courses at MIT. The small class size fosters cooperative learning, collaborative discussion skills, and leadership in group settings. Frequent in-class writing and oral presentations stimulate peer review from which students develop critical analytical skills for assessing the work of others as well as their own. Practica classes are taught in specially designed electronic seminar rooms using file sharing software developed for these classes to support the creation, exchange, display, and annotation of work. The practicum attached to the *Experiments/ Projects Lab* also uses the fully distributed computing environment of MIT to support a prototype for a subject-specific World Wide Web online multimedia textbook. This new paradigm which links communication and research instruction, therefore, can transform the typical student experience of an isolated and perhaps passive performance of an assignment or semester-long project into a richly contextualized educational environment into which are mapped the actual demands of professional practice outside the academy.

3.3 Practicum Outline/Format (class scenario)

The *Communications Practicum* meets for two hours once a week. Weekly assignments are closely tied to the cycle of assignments in the *Experimental Projects Lab.* Students are asked to draft an initial statement of project. While this document is all that is required in the engineering class, the practicum students also document the activities (including personal research and social interactions) that go into the formulation of this first assignment. Therefore, they are asked to write a trip report documenting their visit with potential faculty advisors as students review which project they want to work on. To do this, students are given examples of trip reports from industrial sources. Since the trip report is written as a memorandum, the class also studies a suite of memos from two separate case studies, the space shuttle Challenger disaster and the Three Mile Island nuclear reactor failure. The class is asked not only to read and critique these documents but also to revise them in class for discussion and review. As a result of this coupling of writing and engineering classes we have a fluid and transparent modulation from general principles of audience analysis, organizational and managerial competency, analysis and revision of sample texts to a finished document.

Since the next major assignment in the *Experimental Projects Lab is the* project proposal, practicum students first review sample overheads from an online database and a video from an online multimedia textbook of a past oral presentation in the projects lab. Students use these examples to model an oral presentation of the proposal in the practicum which is videotaped. The class then reviews the videotape for discussion of various organizational and presentational strategies. By the fourth week of the semester, therefore, students have not only practiced a range of report types; they have also become familiar with and experienced in the process of peer review and revision, as well as with the creation and use of visuals in project development. All models and drafts of student work are accessible online both in and out of class at anytime anywhere on campus for ease of reference.

From the oral presentation of the proposal to the written proposal students have several weeks in which to compose several drafts of this important document. The practicum class typically (depending on class size) develops several small peer review groups whose goal is to offer intense commentary from several readers on the developing draft. Students switch off leading these discussions and so develop both leadership and collaborate skills. Since a proposal makes coherent not only the focus and objectives of a project but also the related economic, social, and organizational elements necessary for successful implementation, each practicum student submits a detailed resumé for review in class. Students may also be asked to write a letter of recommendation for themselves—a lesson in focusing attention to the key elements of a resumé for a specific audience. Also, as part of peer review students are asked to summarize their commentary in several short memoranda to the instructor. Individual drafts of the proposal are of course also submitted to the instructor for commentary; and since this review process is facilitated online, this cycle of creation, turn in, commentary and return is not tied to the rhythm of weekly class meetings but can be cycled many times outside class before the next meeting. Because of the online software supporting the practicum, class is in a sense always in session.

The same pattern of assignments is repeated for the final requirement of the first semester of the *Experimental Projects Lab*, the final experimental design review – both oral and written.

4. TECHNOLOGIES USED IN PRACTICUM

4.1 Networked Education Online System

The *Communications Practicum is* supported by the Networked Educational Online System (NEOS), a suite of specially designed software programs for the creation, exchange, display, and annotation of work. NEOS was designed and implemented by faculty from the MIT Program in Writing and Humanistic Studies in collaboration with programming staff from MIT's Information Services. The basic NEOS interface is shown in Figure 3. Instructors and students perform various operations upon drafts of work by clicking on the buttons across the top of the NEOS editor window, such as returning a draft to a student ("Return"), submitting a draft to the instructor ("TurnIn"), submitting or picking up a draft for peer review ("Exchange"), reviewing curricular material ("Handouts"), or accessing an online style guide ("Guide").

In the example shown in Figure 3 a student draft has been taken by the instructor who has placed commentary into it by opening a comment window. NEOS also supports a general online style guide which is hyperlinked. If the instructor feels that a student will benefit from reviewing a section of the guide, the instructor can simply cut and paste that hyperlinked button from the guide into the comment window. An example of this appears in Figure 3 (e.g. 2.7 Wordy Prose). Later on, outside of class, when the student picks up this annotated paper, a simple click of the mouse button on this pasted-in button will automatically call up the relevant section of the guide for review. A sample page from the online style guide is shown in Figure 4.

4.2 The **Physical Space** of Instruction

The practicum class meets weekly in a specially designed electronic seminar room outfitted with twenty Sun Spare workstations which circle the outer perimeter of the room, as shown in Figure 5. At the center of this

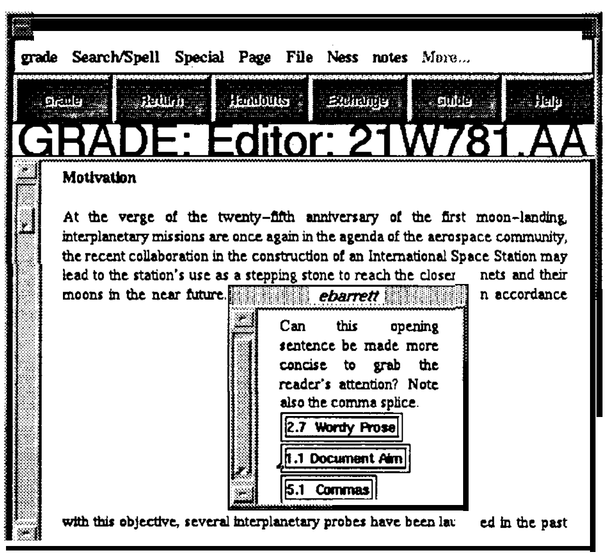


Figure 3: An sample NEOS interface.

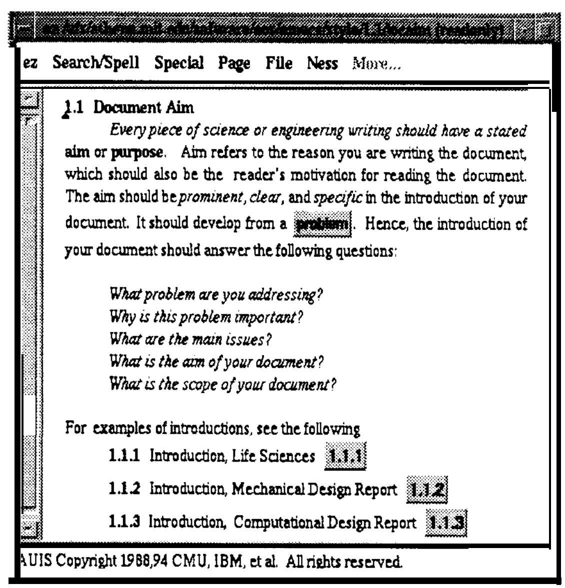


Figure 4: Sample entry from the NEOS online style guide for engineering writing showing hyperlinked entries.

space is a traditional seminar table; chairs on rollers allow students to move easily from face-to-face discussion around the seminar table back to their workstations for in-class writing assignments or to review other material online. In addition, the seminar room is outfitted with an overhead projector which displays the content of the instructor's workstation on a large screen at one side of the room for all the class to see. The overhead projector and display screen are powerful focusing agents for in-class discussion. Student papers or other curricular material can be called up, displayed, and then edited during class allowing students to see the effects of their revisions on a general audience[9].

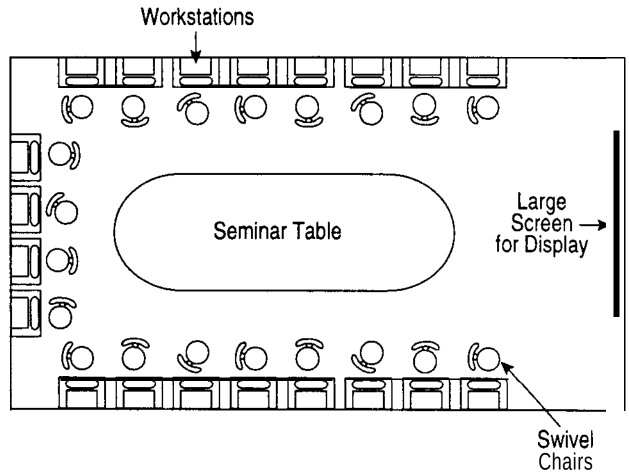


Figure 5: Schematic showing the design of the electronic seminar room used for teaching the communications practicum.

NEOS and the electronic seminar room support a flexible modulation between elements of the traditional lecture presentation to in-class practice in real time. In the traditional classroom, for example, an instructor may present material for discussion with the expectation that students will take this information back to their private workspace for either revision or the completion of an assignment modeled on the classroom presentation. This out-of-class work is then brought back at a later class meeting for discussion, and it maybe another week before the student receives the instructor's handwritten notes on this work. In the electronic environment of the specially designed practicum class this material can be presented in class and then students can move easily to their workstations to compose their assignment while the lecture is still fresh in their minds. These drafts can be submitted in class and instantly reviewed. Since students can store all this material in their home directories, they have ready access to it outside of class for further revision. With NEOS the class is virtually in session all the time, so individual students may exchange work with their peers or with the instructor at anytime for another cycle of review, commentary, and return. More work gets done—that is, students can practice their skills more—in this environment because the mechanics of exchange and annotation are so easy[10,11].

4.3 A **Hypermedia** Textbook

Another important instructional tool used in the *Communications Practicum is* the Electronic Multimedia Online Textbook in Engineering (EMOTE). EMOTE is a prototype for a subject-specific hypermedia "textbook" for aerospace communication.* Unlike NEOS, which is tailored to the computing environment of MIT, EMOTE has been implemented on the World Wide Web (http: //web. mit.edu/emote/emote.html) and is, therefore, potentially accessible to engineering students or practicing engineers throughout the world.

EMOTE presents students with specific report models (written and oral) and accompanying commentary. Since EMOTE is a multimedia document, students have access to a full range of graphics, as well as audio and video clips for instruction in oral presentations, as shown in Figure 6.

Practicum students, in end-of-semester evaluations, have said that EMOTE was a valuable instructional tool and that they were especially pleased that it could be accessed easily under the pressure of deadlines when they were in the midst of composition. This anecdotal evidence suggests that MIT students use the written and

* Developed by Barrett and Waitz with the assistance of 16.621 students; initial design consultation from Dr. Janet Murray, MIT; HTML implementation by Sean Chiu (MIT, '96). Supported by a grant from the MIT Class of 1951 Fund for Excellence in Teaching.

oral presentation models in EMOTE to help them discover their own compositional and communicative strategies. EMOTE provides practical and accessible heuristics for helping students explore their own ideas.

In the future we would like to merge the multimedia functionality of EMOTE, the world-wide accessibility of the Internet, and the supple annotation functions of NEOS to create a highly tailorable and functional instructional tool.

5. ASSESSMENT

Because the Communications *Practicum* structure is experimental we have tracked its evolution with end-of-semester student evaluations created specially for the practicum. The *Experimental Projects Lab* was evaluated using Institute-wide, Course Evaluation Guide forms. Each form asks students to indicate their reactions to various questions by means of a numerical designation, as well as by means of written responses to questions about the course.

Figure 7 is a bar chart depicting mean responses (on a O to 5 point scale, with 5 as the highest or most favorable) on the practicum-specific questionnaire for three sections of the practicum offered during the Spring 95 and Fall 95 academic terms.

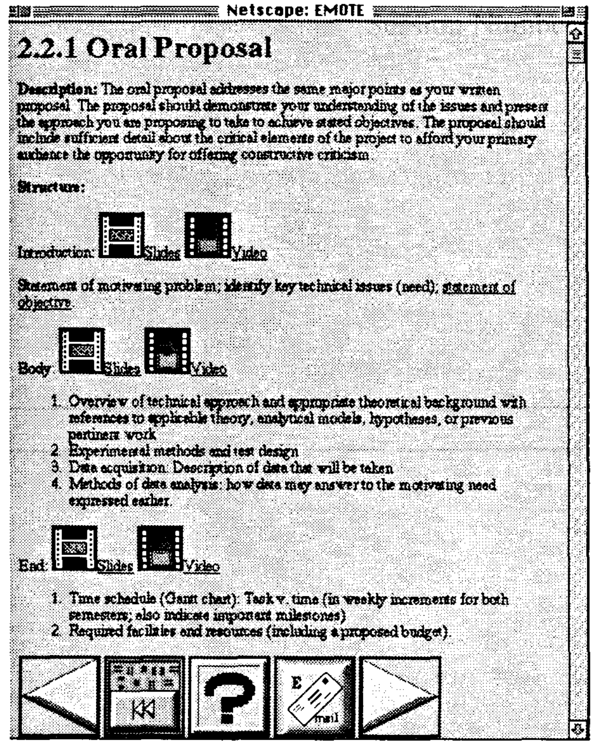


Figure 6: EMOTE screen for access to video and audio of a model student oral presentation of a proposal.

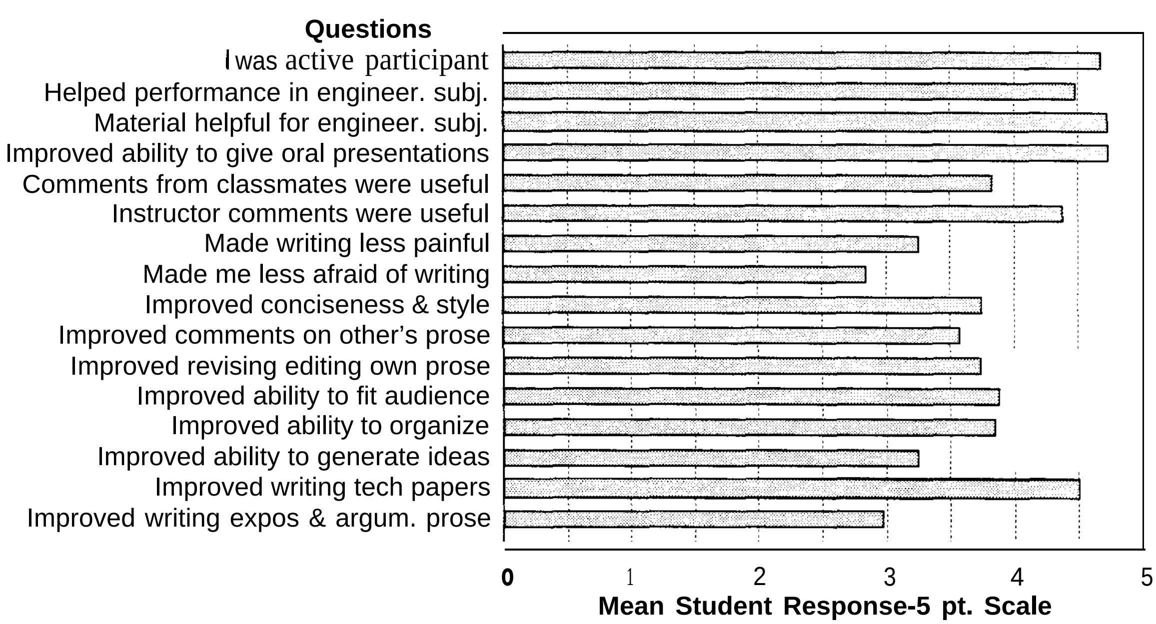


Figure 7: Mean responses for the practicum-specific questionnaire for Spring and Fall 95 sections of the *Communications Practicum.*

The responses indicate that students felt the practicum subject improved performance in the *Experimental Projects Lab.* Students felt strongly that the practicum class improved their overall communication skills (written and oral), as well as their ability to comment on other's prose and to revise their own prose. Critical organizational skills were also felt to have been improved, with even a moderate expansion of this sense of improvement to less subject-specific kinds of expository and argumentative prose. Additionally, students felt that their practicum training gave them critical peer review and collaborative skills.

General satisfaction was also expressed in the student evaluations of the *Experimental Projects Lab.* The overall course ratings for the last three years have averaged 5.5 for the first semester of the course and 6.0 for the second semester of the course, both on a scale of O to 7. Students describe it as a "learning by doing class" and note "This is where everything you learn comes together," Other comments include "At last, practical experience," ". . . the most time consuming class that I have taken so far, but it was worth it. Togo through the process of designing an experiment, building it, testing it, and analyzing the results was very beneficial," "This was by far the class [in which] I have learned the most about design. I've enjoyed the class tremendously, and wish there were more like it at MIT," and "It's the closest thing to real engineering I've encountered."

6. SUMMARY AND CONCLUSIONS

This paper described the coupling of an undergraduate *Experimental Projects Lab* with a *Communications Practicum.* The interdependence of clear thought and clear expression provided the motivation for the joint teaching of these two subjects. Written and oral assignments developed, shaped, and peer reviewed as part of the practicum, are used to satisfy the written and oral requirements for the experimental projects subject. Modern information technologies are employed to enhance the effectiveness of the practicum. The joint course structure serves to educate students in a variety of aspects of professional practice including solving open-ended problems, system-level integration of disciplinary coursework, project development and planning, oral and written communication, peer review and teamwork. Several pedagogical themes underlie the two courses including hands-on learning, cooperative education, writing-to-learn, and mentoring.

After three years we have found the pairing of the *Experimental Projects Lab* and the *Communications Practicum* to be mutually beneficial. Both the quality of the research performed and the students' ability to transmit an understanding of that research to others have been enhanced. End-of-semester student course evaluations reveal a high level of student satisfaction with this new model.

7. ACKNOWLEDGMENTS

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