WEB-BASED ALTERNATIVES FOR LEARNING ENGINEERING SCIENCE

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ABSTRACT

As curricula receive increasing pressure to reduce credit hours while including non-traditional elements, the engineering science component has sometimes been the target of cutbacks. However, knowledge of the fundamental concepts remains critical to engineering education. The existing paradigm for teaching engineering science is three credit hour blocks of material. This three-unit course depth may not be necessary, but a basic comprehension of the material is vital.

Over the past four years, eight faculty members in the College of Engineering and Mines (COEM) at the University of Arizona have created a web-based course, ENGR 211. The course consists of eight 1-credit hour modules on engineering science topics and spans the areas traditionally covered by the Fundamentals of Engineering professional exam (statics, thermo, dynamics, fluids, mechanics, materials, electric circuits, and economics). The modules are now part of the required curricula in 2 departments and demand from a variety of sources is rising rapidly (75 credit hours during Fall 2002, 100 registered for Spring 2003). In this paper, we describe the overall system used in the course, the methods of delivery and student support, and a comparison of learning outcome measurements from the traditional 3-unit classes. We also include discussion on our experiences with the difficulties of running such a class.

INTRODUCTION

In Spring 1998, the University of Arizona (UA), College of Engineering and Mines (COEM) using a grant from the General Electric (GE) Foundation started on the development of 1-credit web based modules on various topics of engineering science. The "need" for these modules is a direct result of a University mandate to reduce credit hours in all programs (or advertise as a 5-year program). Each department in the COEM was required to reduce degree requirements to 128 credits or less. The strategy of most of the programs was to cut out materials that were not directly related to the major. Note that the general engineering science courses at the UA are typically 3 credits (45 hours of class meeting time during the semester). So, if a department wanted a breadth of engineering science - for example, material on statics, dynamics, electronic circuits, and engineering economics - then they would have to take a battery of four 3-credit courses. We do not mean to say that the materials in these courses are not necessary, but for some majors, three credits of one topic may be less preferred to one credit (15 hours) in each of three topics. Breadth may be better than depth for some majors and some topics. Since 1998, the project has also been supported by the General Electric Foundation, the COEM, and the Arizona Board of Regents. A rough estimate on direct costs for development and 3 offerings to date is $400,000. This does not include faculty time that has been donated during the course offerings or time beyond what was funded for development.

Our approach is to use web technology as a learning platform. This decsion is motivated by constraints on faculty time and a student body that appreciates time flexibility. The intent is to develop "stand-alone" modules where students can access the materials at any time, be tested for pre-requisite materials, have progress monitored, and be examined at the conclusion of the module. We are striving to have materials that can be used by teaching assistants with little faculty oversight. We chose engineering science topics since this is where breadth is needed, and it is a body of material that is relatively stable. Also, our faculty members that were interested in developing the content materials generally taught these classes (among others). Finally, these topics in a web based system could be easily and effectively used by advanced students as a refresher course of the Fundamentals of Engineering Exam.

The remainder of the paper is organized as follows. In the next section, we will give a brief overview of our progress on the entire set of modules and our course set-up. In the following section, we give examples of the types of materials that we include, the navigation interface, and the flexibility in the system. The entire suite has been offered for 5 semesters. Our course setup and the results of our evaluation of learning outcomes are covered in final two sections, respectively. Our primary evaluation is to compare scores on final exam questions of ENGR 211 students with scores on identical (or in some cases similar) exam questions for students in the traditional 3-credit classes . We conclude with the changes we will make based on the evaluation and directions for further experiments.

PROGRESS ON THE MODULES AND COURSE SET-UP

The modules cover the following topics:

- Statics
- Engineering Economics
- Mechanics of Materials
- Electronic Circuits
- Materials Science
- Hydraulics and Fluid Mechanics
- Thermodynamics
- Dynamics

A team of faculty and students, used a curriculum development process (developed primarily by Dr. Elena Berman of the UA Faculty Center for Instruction Improvement) to specify the content for each module and the results of the process was a content map of topics and the time required for students to complete each block on the map . The content map is now used as the primary site navigation tool. A faculty member was responsible for developing the content material for site development team. The site development team consisted of a team leader and a crew of undergraduate students and they were responsible for putting the content on the web and ensuring that the navigation tools work. Over the life of the project, we have had over 25 graduate and undergraduate students working on content development.

Our on-line system includes:

- blocks of course content,
- a course registration and security software,
- an exam module for constructing quizzes and providing grading and answer feedback, and
- a database for storing student answers to learning exercises, student opinions on the site, time spent on the site, and student responses to quiz questions.

A graduate student developed much of the inner workings of the system. Each semester we manually enter the students registered in the class (we cannot yet link easily to the UA registration system as there are security issues on their end). The students are then informed using email that they must go to our site and set up a userid and password. Upon setup, we also collect baseline evaluation data from each student (major, standing, email, GPA, experience level with web courses, home PC).

The semester is broken into three 5-week blocks and a subset of the modules are offered in each block. We have a fixed start and stop date for each block and this allows the teaching faculty and the students to manage time better. Each module has two graded events; 1 homework assignment (30% of course grade) and 1 final exam (70% of course grade). The homework is due at the end of the 3rd week and is graded by the end of the 4th week. The final is taken live and the student must present a picture ID at the exam. We have not solved the exam security problem, so we simply have the students sit for an exam. Off campus students can use proctors for exams. A Teaching Assistant runs the course and interacts with the students and the faculty developers. Faculty input is rather light and consists of providing homework and exam questions, advice on final grades, and dealing with web site content errors if they occur. The development team has a weekly meeting to discuss how the current semester is going and what portions of the site should be changed and improved.

We ran 6 modules in Fall 2001 and the final 2 (circuits and dynamics) were first run in Spring 2002. We ran all 8 modules Fall 2002. Though our instructors thought that the materials were complete, students taking the classes did not have the same opinion. Initial comments from students strongly suggested that more examples were needed. The major editing includes additional worked out examples, including more animation and graphics to explain concepts, and including more quiz questions and answers. Using the course TA as team lead and 5 undergraduates we continue to edit and update the materials and to manage the class.

ENGR 211 is part of the required curricula for degrees in industrial engineering and civil engineering. The courses can be used to satisfy engineering science electives in system engineering, engineering management, and the BA in engineering degree. We are currently working with chemical engineering, electrical engineering, and materials science to see where the modules might be of interest. Enrollment has steadily increased. In Spring 2002, we had 60 credits of registration and gave out 45 grades at the end of the semester. In Fall 2002, we had 82 credits of registration and gave out 70 grades at the end. The registration for Spring 2003 is 95 credits as of January 5th, 2003. We will discuss the retention issues in the final section.

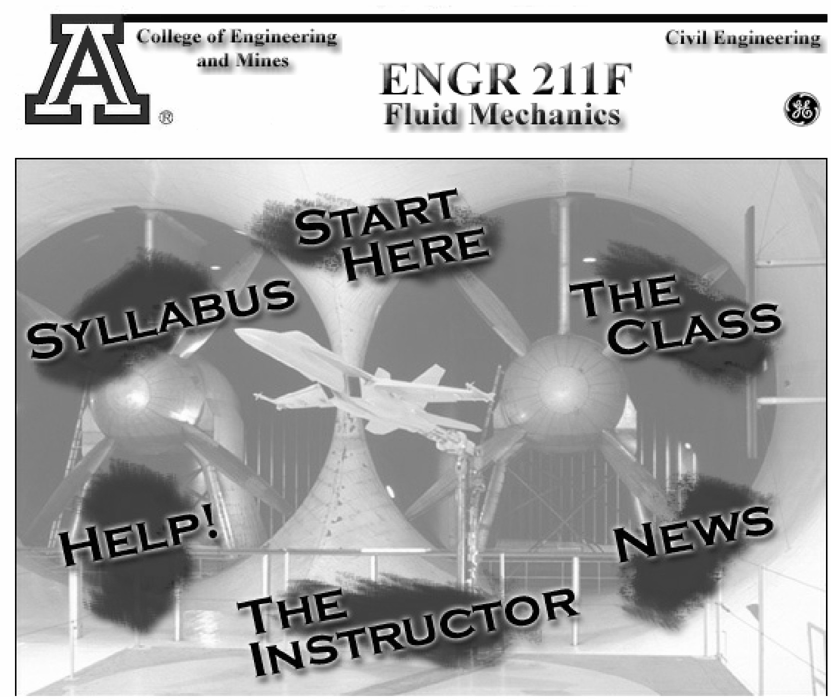

Figure 1 - Module Wheel

MODULE DESIGN AND PEDAGOGICAL APPROACHES

The front page for the modules can be found at http://gecourses.sie.arizona.edu/GE. To access the sites a username and password are required and this can be obtained by e-mailing Jeff Goldberg at jeff@sie.arizona.edu. Each module starts with an initial page called the "module wheel" that contains information on course structure, the instructor, navigational help, course newsgroup, and course material (Figure 1 for ENGR 211F - Fluid Mechanics). The student creates a user-id and password at the "START HERE" button.

The class is organized using a "course map" and each topic is a block on the map (Figure 2 for ENGR 211I - Dynamics). To access the map, the student must provide a user-id and password. They then proceed through the material at their own pace. Also, on the bottom navigation bar there are links to a print engine, a search engine for looking up topics, the class newsgroup, and email to the TA and the instructor. All of the modules have the same interface and the same organization style so there is no additional learning required to access other modules.

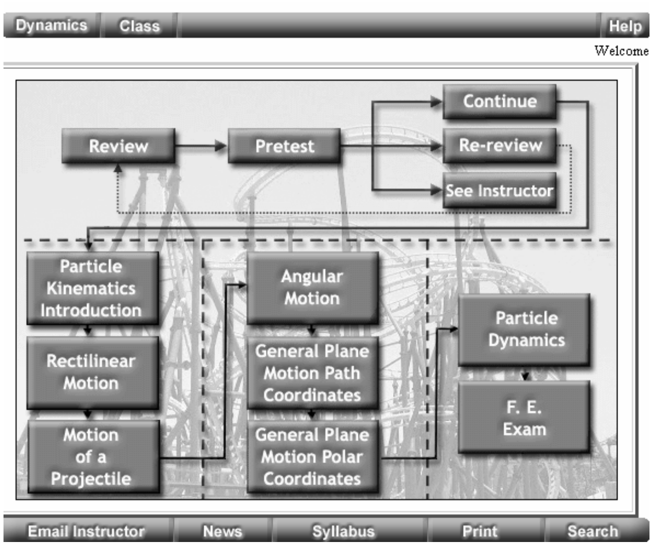

Figure 2 - Course Map

Our interface is designed to make things easy for the student and is broadly consistent. For example, we use common colors for different functions (all active links are blue and underlined in every module, no other blue and no other underlines). We try to fit all pages on one screen so there is little or no scrolling (designed for a 15 inch monitor). Downloads are small and can be handled by a 56K connection (for video's we give an option to download with a high speed connection if that is available). We tell the student how many screens are in each block and hence the student can estimate the time required for completion.

In Figure 3, we give a typical page in our engineering economics module (ENGR 211 P). The top bar allows students to get to the module wheel ("Economics" button), the module map ("Class" button), the section first page ("Taxes and Depreciation" button), and the pages within this particular subsection (buttons numbered 1 through 10). There are next and previous buttons on the label bars (this is the first page in the subsection so there is no previous page) and this page has a video clip denoted by the music/video icon. The bottom bar is the same on all pages and has been described previously. Note that our video clips are created using Windows Media and only work when using Windows Internet Explorer.

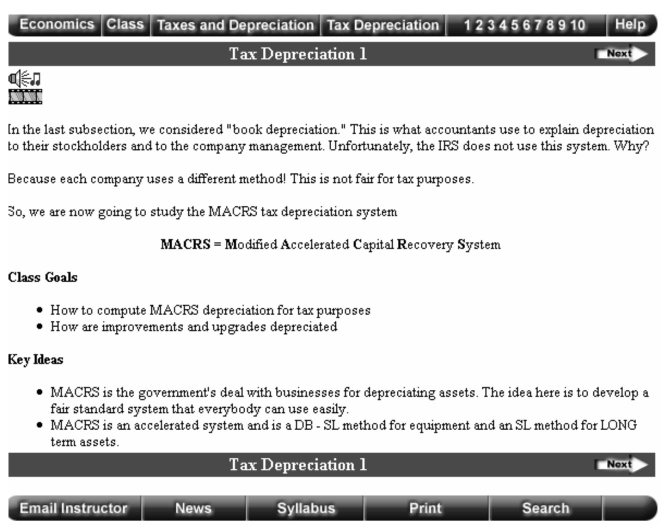

Figure 3 - Navigation and Audio/Video Button

Figure 4 is a page from the Materials Science module and includes a flash animation icon used throughout all of the modules. Note that here there is no subsection, so the page numbers represent the 5 pages within the section. The quiz button on the bottom bar links to a quiz for the particular section. The “help” button on the top bar links to navigation help and icon recognition help.

Within each module, there are a variety of pedagogies used to facilitate learning for all types of learners. These include:

- Text materials and static images/graphs to explain key points;
- FLASH animations to demonstrate dynamic events and actions;
- Screen rollover buttons that dynamically change portions of the screen and help to explain the particular area the student is studying;
- Spreadsheets to enable experimentation with equations;
- Complete examples on each topic;
- Dialog boxes to enable students to respond to questions during studying;
- Audio clips containing explanations of materials (usually example solutions);
- Audio/Video clips containing explanations of the materials (usually an example worked out on the board or motivational material);
- Glossary of formulas and terms in the class;
- Quizzes – immediately graded and solutions are given to the student (grades are stored by user-id and can be accessed by the TA and the instructor). These can be accessed in each block or can be accessed using the “FE Exam” block on the far right of the module map. Figure 5 is an "end of section" page from the Engineering Economics module. Here we ask the student for feedback on the site and provide an opportunity for solving additional problems. This type of dialog box is used for asking students technical questions as they are reading and working through the sites;

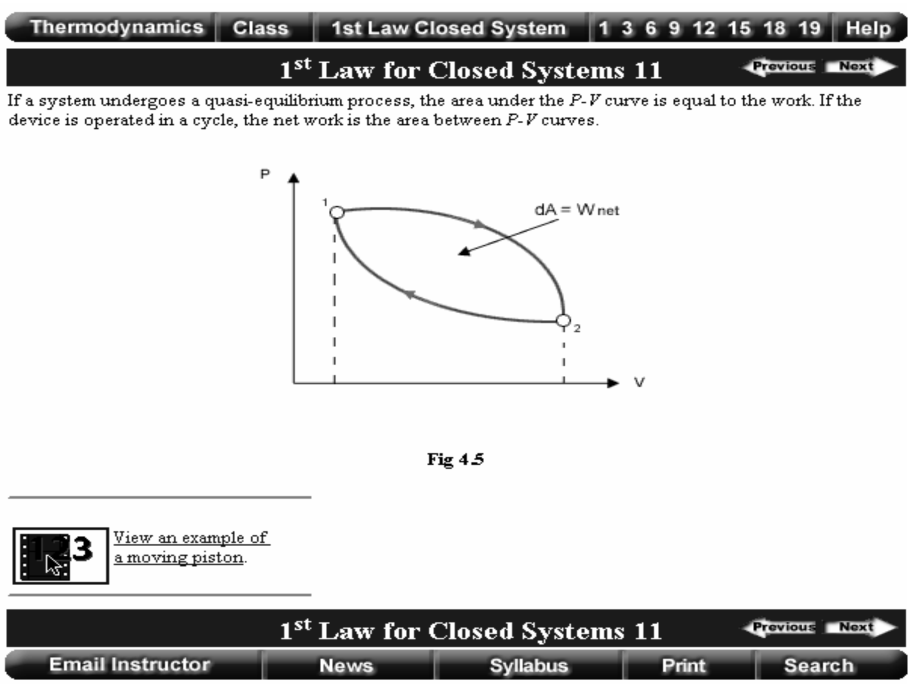

Figure 4 - Navigation and Flash Examples

- A search engine for quickly looking up keywords and topics;
- Newsgroups and email to facilitate discussions and student questions; and
- Navigational help and an email link to the system manager if there is an access problem.

The material is largely designed for independent learning by the student; however we also provide regular TA office hours, a weekly help session if necessary, and pre-exam review sessions. The student controls the pace and direction of the class, but all material must be eventually covered. We have the option of locking parts of the module away from a student until the pass a quiz signifying progress on earlier sections, but initial efforts on test students suggested that students would rather have access to the entire site.

Figure 5 - End of Section Feedback and Quiz Links

EVALUATION

We have students fill out an attitudinal survey at the completion of each module. The survey questions focus on the students' perceptions of learning, time spent on the class, difficulty, and how using the technology affects difficulty and learning. We have been using the survey for the past 2 years and it is the key tool used for charting directions for site improvement.

We evaluate student learning by comparing the results on ENGR 211 final exam questions with results on exam questions from the traditional engineering science courses. We have done this with identical question comparisons in statics, engineering economics, fluids, circuits, materials, and mechanics. Typically, the ENGR 211 final contains at least 2 or three questions that have been used in the traditional course.

Our goal is to show that students are learning and what the students are learning in ENGR 211. We are trying to demonstrate the feasibility and low cost of a web based approach and not to show that the web-based approach is better or worse than the traditional approach. This type of exam question comparison by itself really cannot be used in a better/worse comparison due to the following complications:

- The abilities, maturity levels, and educational goals of the students in the traditional classes are significantly different than the students in ENGR 211. For example, in ENGR 211C - Statics, the students are typically industrial engineering sophomores and the class is low priority compared to classes in major. The traditional class, CE 214 - Statics, is largely civil and mechanical engineering sophomores and this is the critical foundation class for their junior and senior level classes. In comparison, ENGR 211P - Economics typically has civil engineering seniors while the traditional course SIE 265 - Engineering Management I, has systems and industrial engineering and engineering management sophomores. The point is that when there are differences in exam scores, it is not clear if this is due to the differences in the students or to the differences in the teaching approach.

- The scores on exam questions are not independent since the exams have a time limit. This seems to be more critical in the traditional classes based on student comments. We compare scores on a question by question basis and not on the entire exam. The problem is that a score on a question could be lower if it is on an exam with more difficult or more time consuming questions. Since material in ENGR 211 is spread throughout the traditional courses (we are not simply doing the first 5 weeks), it would require a complete special exam in the traditional classes to make a more valid comparison.

Despite the problems with the experiment structure, we feel that the approach has validity in seeing the success in the approach. If the 211 students are doing substantially worse than the traditional classes on questions that we feel are important, then this would suggest that the web-based approach is not working well for this group.

In this paper, we report only on exam comparisons for ENGR 211P - Engineering Economics with SIE 265 Engineering Management I, and for ENGR 211R - Materials Science with MSE 331R - Fundamentals of Materials for Engineers. They are typical of results that we have seen in the other modules. In both of these classes, the instructor graded their class exam as well as the ENGR 211 final exam to ensure a consistent scoring rubric.

The 211P exam consisted of 6 questions and all 6 were used in SIE 265 exams (2 questions from each of the 3 course exams). The questions are typical engineering economics exams covering economic insight (question 1), developing income and cash flow statements (question 2), cost estimation and inflation (question 3), breakeven problems (question 4), equivalence and loan computations (question 5), and rate of return computation and analysis (question 6). The problems require skills in recognizing the correct approach, using the appropriate problem data, correctly implementing the approach, and making the appropriate conclusions. The results are in Table 1.

Problem	1	2	3	4	5	6	Total
Max Score	24	50	40	30	25	35	204
SIE 265 - 34 students Spring 2002							
Average	18	38	35	21	16	23	150
Median	19	44	37	26	17	25	152
Standard Deviation	4	13	7	9	7	9	34
ENGR 211 P - 10 students Fall 2002							
Average	16	39	37	25	16	22	155
Median	18	45	39	28	17	23	163
Standard Deviation	6	14	3	6	6	9	27

Table 1 - Exam Results - Engineering Economic

Class	Average Cum GPA	Sample Standard Deviation	Sample Size	Standard error of the sample average
SIE 265	2.67	0.523	34	0.090
ENGR 211P	2.74	0.481	10	0.152

We think that it is safe to say that the total scores as well as the scores on individual questions from the 2 groups are similar and that the web-based approach is working for the Fall 2002 ENGR 211P group. If we delete the two weakest scores in the SIE 265 sample group both students scored below 65 total points),then the two groups yield almost identical statistics. Since it is possible that the 211 students in this group are just better students, we compared the cumulative GPA's of the two groups.

We cannot reject a hypothesis that the mean GPA's of the two classes are different and this gives more credibility that the closeness of the scores suggests that the students were learning similar amounts.

A different exam structure was used in ENGR 211R - MSE 331R. Here, the instructor uses a mix of multiple choice questions and problems as this is appropriate for course goals (this particular module has a large number of drawings and rollover images as visual acuity on material structure and phase diagrams are key learning outcomes). The material in ENGR 211R is largely contained in the 2^{nd} third of MSE 331R so, a subset of the 331R 2^{nd} midterm exam was used for the final exam in 2llR. The 211 final contained 7 multiple choice questions and 3 problems. The ENGR 211R students were asked to do 2 out of the 3 problems (problem 1 is an alloy problem, problem 2 is a diffusion coefficient problem while problem 3 is a phase diagram problem) while the MSE 331R students had a larger selection and had to do more problems. Since every student did not do the same problems, we do not total scores on this section of the test. The comparisons are made only over the students that did each specific problem. The results for the two sections are in Tables 2 and 3.

Multiple Choice	1	2	3	4	5	6	7	Total
Max Score	2	2	2	2	2	2	2	14
MSE 331R - 21 students Fall 2002								
Average	1.52	1.71	1.43	1.62	1.62	1.05	2.00	10.95
ENGR 211 R - 5 students Fall 2002								
Average	0.40	0.40	2.00	1.20	1.60	0.80	1.60	8.00

Table 2 - Exam Results - Materials Science (Multiple Choice)

Problem Max Score	1 10	2 10	2 10
MSE 331R - 21 students Fall 2002			
Average	8.42	7.25	7.95
ENGR 211 R - 5 students Fall 2002			
Average	7.60	3.75	8.63

Table 3 - Exam Results - Materials Science (Problems)

As compared to engineering economics, the picture here is cloudy and there is an additional confounding factor. We have a small but complete sample for ENGR 211R, but we only have scores from 21 out of 95 students in MSE 331R. These students self selected to report and it was clear that better students reported. The course grades for the reporting group was 13 A's, 7B's, and 1C. The course grades for the entire class was split almost equally between A's, B's, and C's. So, it seems that the MSE 331R reporting group is better in the material than the typical class.

It is clear that the 211R group had some gaps in learning the material. For example, on multiple choice questions 1 and 2 only 1 of the 5 students got the answer, while more than 3 out of 4 got it in the traditional class. Two students in ENGR 211R attempted problem 2 and neither scored well. Since this was a do "2 out of 3" exam and the students selected the problem even though they were weak, one can presume that they really did not know 2 of the 3 problems (we assume that the students actually realized correctly that they knew little about the problem). On a positive note all five ENGR 211 students attempted problem 1 and scored similarly to those in this selective group in MSE 331R. It is clear that learning is occurring in ENGR 211R, but it is also clear that there are gaps and these are due to the web site deficiencies or student learning process deficiencies.

DISCUSSION AND EXPERIENCE

Overall we believe that the project is successful and we finally are at the point where benefits start to accrue. We have incurred a large fixed cost both in dollars and in development time but we now can run quality classes with significantly lower costs. The project has had some bumps in the road and we have learned a great deal in the process.

In our initial offerings we had a large retention problem. Students invariably waited until the final weekend before the exam to cover the material and this simply was not enough time. Signing drop forms on the day of the final exam was common. Notes from students in the 4th week of the block saying "what am I supposed to do for this class?" were also common. Most of these problems have been solved by extensive communication processes between the TAs and the students. Emails to students every few days, announcements to the class before the semester starts, an emailed syllabus and navigation write-up before the first day of class, and direct links to the class site from the University catalog are necessary to ensure that students have the information needed to be successful in the class. We schedule each block 2 months before the start of the semester and this includes the modules to be offered, the homework due date, and the final exam date. Advanced planning helps our faculty and our students.

During the first course offerings, one should be prepared for predominantly negative feedback from students. The interface is not good enough, material is confusing, there are not enough examples, … the list goes on. Much of this criticism is valid and some is due to the newness of this type of learning experience. We have found many students that, at this point, do not seem to be able to learn well in this manner with our materials. Frustration levels can be exceedingly high and hence instructor flexibility and understanding is required. We are still at the experimental stage with the approach and it is clear that just like in the traditional classrooms, all students use different learning methods.

Much of our cost benefit comes from having graduate students primarily responsible for running the class as they are lower in cost than tenured faculty. It is critical that the TA's be highly ethical, have good communication skills, have a breadth of technical skills, and be well organized. We have found that generally the slowest links in the processes are the faculty members. It requires time to organize exams and homework and if the TA does not have good foresight and scheduling ability, everything is a last minute rush. We have run for 3 semesters and hence we are developing a history and set of processes, but still the TA's are the key piece of the solution as they implement the process. Breadth of knowledge is critical, especially as more modules are run simultaneously (few students are excellent in all areas of engineering science).

When starting these types of projects, one should be prepared for cost overruns and skepticism from faculty. One of our key strengths was that we obtained buy-in from the instructors of the traditional classes before we started development. Also, we started with modules where we already had partially developed materials (economics and statics) and these sites have been the technology leaders where we experiment with new ideas.

BIBLIOGRAPHY

1. J. Goldberg "Engineering Economics on the Web - Progress Report", ASEE/IEEE Frontiers in Education Conference, Phoenix, AZ, 1998.

2. J. Goldberg, "Engineering Economics on the Web", ASEE Conference Proceedings, Session 3557 Charlotte, NC. 1999.

3. J. Goldberg, M. Hickman, and K. Lansey, "Web-Based Engineering Science Course Modules", Session 2793, ASEE Conference Proceedings, Albuquerque NM, 2001.

BIOGRAPHICAL INFORMATION

Jeff Goldberg is an Associate Professor in Systems and Industrial Engineering at the University of Arizona. He also serves as director of the BA in Engineering Program and is a past Associate Editor of Engineering Education. Jeff has taught two other courses primarily using web technology. His research areas are applied mathematical modeling and engineering education.

Kevin Lansey is a Professor in Civil Engineering and Engineering Mechanics at the University of Arizona. He was one of the principal investigators on the GE project and created the module on fluid mechanics and hydraulics. Kevin was the College of Engineering and Mines Team Leader for a successful ABET 2000 visit in fall 1998. His research area is systems analysis applied to water resources.