AC 2009-1417: EFFICIENT TEACHING OF ELEMENTARY ENGINEERING MECHANICS COURSES

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Efficient Teaching of Elementary Engineering Mechanics Courses

Abstract

Elementary Engineering Mechanics classes (i.e. Statics, Dynamics, and Mechanics of Materials) provide an integral portion of lower division engineering curricula for Civil, Mechanical, and Manufacturing Engineering. These courses are crucial in the engineering education process for these disciplines because they introduce students to the engineering approach in problem solving, provide basic principles that are used in following courses, and let lower division students recognize if they are equipped for an engineering curricula. In addition, many questions for the Fundamentals of Engineering exam have their roots in these courses.

Providing the proper teaching environment for these courses is a challenge for faculty and department administrations because a) there are numerous students that must be accommodated, b) the students deserve a quality experience to both introduce them to the engineering curriculum and to give them a positive encounter in the major, and c) the content of these courses forms the necessary foundation for numerous follow on courses. However, research and other demands on faculty may challenge a department's ability to place appropriate faculty in these classes. This paper relates the evolution from teaching numerous sections of these classes, through the consolidation into large classes and eventually the incorporation of very effective and efficient student-to-student mentoring in conjunction with the large section instruction.

During the last fifty years the teaching of Elementary Engineering Mechanics courses at our university has continually evolved due to increasing enrollment pressures and higher expectations for faculty research productivity. This has resulted in a cost effective system of instruction involving at most two sections each of the Engineering Mechanics - Statics, Engineering Mechanics - Mechanics of Materials, and Engineering Mechanics - Dynamics classes. Students in these classes are provided with extensive class notes and exam file, and access to the Engineering Mechanics Instructional Laboratory (EMIL). This student run facility typically has eighteen student teaching assistants which provides full tutoring coverage as well as grading of homework and examinations. Faculty involvement is limited to sixteen lecture hours per week and supervision of the examination grading process. During a typical Fall or Winter Semester this system serves approximately six hundred students.

Success of this teaching effort is assessed by student questionnaires about the EMIL operations, scores of student's Fundamentals of Engineering (FE) exam, student course evaluations, and department exit interviews. Student questionnaires indicate that 79% of the students regularly use the EMIL and that 97% of the students rate the quality of the tutorial service either good or excellent. Students from our program pass the FE exam at a rate higher than the national average and student course evaluations and data from exit interviews indicate that understanding engineering fundamentals (i.e. engineering mechanics) is among the highest rated aspects of our program.

Key Words: Mechanics, Instruction, Mentoring

Introduction

Statics, Dynamics, and Mechanics of Materials are basic engineering mechanics classes that provide many of the fundamentals for a civil and mechanical engineering curriculum. Challenges that are associated with teaching these courses include a) accommodating the large number of students that must be taught, b) the need for a quality experience to both introduce students to the engineering curriculum and give them a positive encounter with the major, c) ensuring the content of these courses form the necessary foundation for numerous follow on courses and d) efficiently using faculty resources to integrate classroom lecture, teaching assistant training, and interactive problem solving experiences for students. This paper describes the evolution of the engineering mechanics program at our university. Initially the program used small sized mechanics classes (approximately 35 students) that were taught by a several faculty members, each faculty supported by a single student teaching assistant. The program currently uses only one full time and one part time faculty member and a highly organized group of teaching assistants. These teaching assistants have a strong mentoring experience both from the faculty they serve and the students they teach. This current program allows for effective classroom teaching supported by a problem solving laboratory that allows powerful student to student mentoring.

Springer, Stanne and Donovan[1] provided an extensive study on the effects of small group learning. Their National Science Foundation study concluded small-group learning is effective in undergraduate science, math, engineering and technology courses. Their results suggested that students who learn in small groups generally demonstrate greater academic achievement, express more favorable attitudes toward learning, and persist through these courses more than their traditionally taught counterparts. In an effort to understand how to improve the quality of undergraduate student experiences, Fisher and Fairweather[2] studied how to upgrade engineering service courses. They report several lessons learned in efforts to prepare for the ABET 2000[3] review. In a study to determine the effects of using of microcomputer based laboratories as a component in mechanics courses, Bernhard[4] determined that, without using sound pedagogy, microcomputer based laboratories are only marginally better than traditional teaching. However, in another study, Berhnard[5] reports that "active engagement" curricula are much more effective in fostering a good understanding in mechanics concepts. This finding was also supported in the work by Francis, Adams, and Noonan.[6] It has been reported by Ellis, Scordilis and Cooke[7], that a learner-centered approach to teaching introductory mechanics courses has been effective for women engineering students. The issue of small verse large size mechanics classes has been discussed by Rahman, Papadopoulos, and Malhas[8], but no indication as to which model is most effective was concluded. More recently, Glynn, Dinehart, and Gross[9] are studying the concept of teaching mechanics courses in a problem-structured environment wherein topics are clustered into thematic groups focusing on a single problem. These problems are formulated to help students visualize connectivity between specific principles. These problems serve as a framework to introduce students to engineering mechanics. Data on student performance using this technique has not yet been gathered.

In this paper we present a model for teaching undergraduate mechanics classes using the efficiency and sound pedagogy of large lecture sections, coupled with a teaching laboratory that effectively incorporates both active student engagement and learner centered activities. Success of this teaching effort is accessed by student questionnaires about the EMIL operations, scores of student's Fundamentals of Engineering (FE) exam, student course evaluations, and department exit interviews

Enrollment Pressures

Our university was founded in 1875 and remained a small school until after the Second World War. From 1946 to 1976, the average daytime enrollment increased almost tenfold. Since the early nineteen eighties, the enrollment has been somewhat stabilized at approximately 33,000 students. The engineering program commenced in the early nineteen fifties. It also started small, but grew with the University and currently has a student body of about 3,200 students. The College of Engineering and Technology is comprised of Chemical Engineering, Civil and Environmental Engineering, Mechanical Engineering, and Electrical and Computer Engineering as well as the School of Technology. The Civil and Environmental Engineering Department has the responsibility to teach the Engineering Mechanics courses for the entire College. Therefore, the Civil and Environmental Engineering students as well as the Mechanical Engineering students all take the same three classes (statics, mechanics of materials, and dynamics), and from within the School of Technology the Manufacturing Engineering Technology students take both statics and mechanics of materials with the engineering students. The College decision to give the Civil and Environmental Engineering Department this overall responsibility has significantly contributed to the economy of the resulting program.

As shown in the five year average enrollment graph, Figure 1, the average mechanics course size was growing modestly but remained under 40 students until in the early nineteen eighties. Then, during the late nineteen eighties and into the early nineteen nineties, the average class size grew to about 100 students per class and has remained approximately at that level. The early growth rate reflected a desire and ability to keep classes small and the average rate of increase was tempered by the fact that sometimes one section of a class was offered and other times two sections were offered. Since the late nineteen nineties, the average class size has slightly reduced and the college enrollment has somewhat stabilized as the number of sections offered for each class has settled on two for the Fall and Winter Semesters and one during either the Spring or Summer Term.

Expectations for Faculty Research Productivity

Until about nineteen eighty, the faculty advancement in rank process, in most academic departments at our university, was relatively informal and based mostly on teaching performance. The requirement for scholarly activity was department dependent and usually minor. The departments within the College of Engineering and Technology had widely varying expectations. Within the Civil and Environmental Engineering Department, these expectations and corresponding achievements were modest. During the early nineteen eighties, scholarly expectations for newer faculty were significantly raised throughout the entire University with the introduction and enforcement of formal retention and rank advancement review procedures. Corresponding increases in faculty resources, however, were not immediately forthcoming.

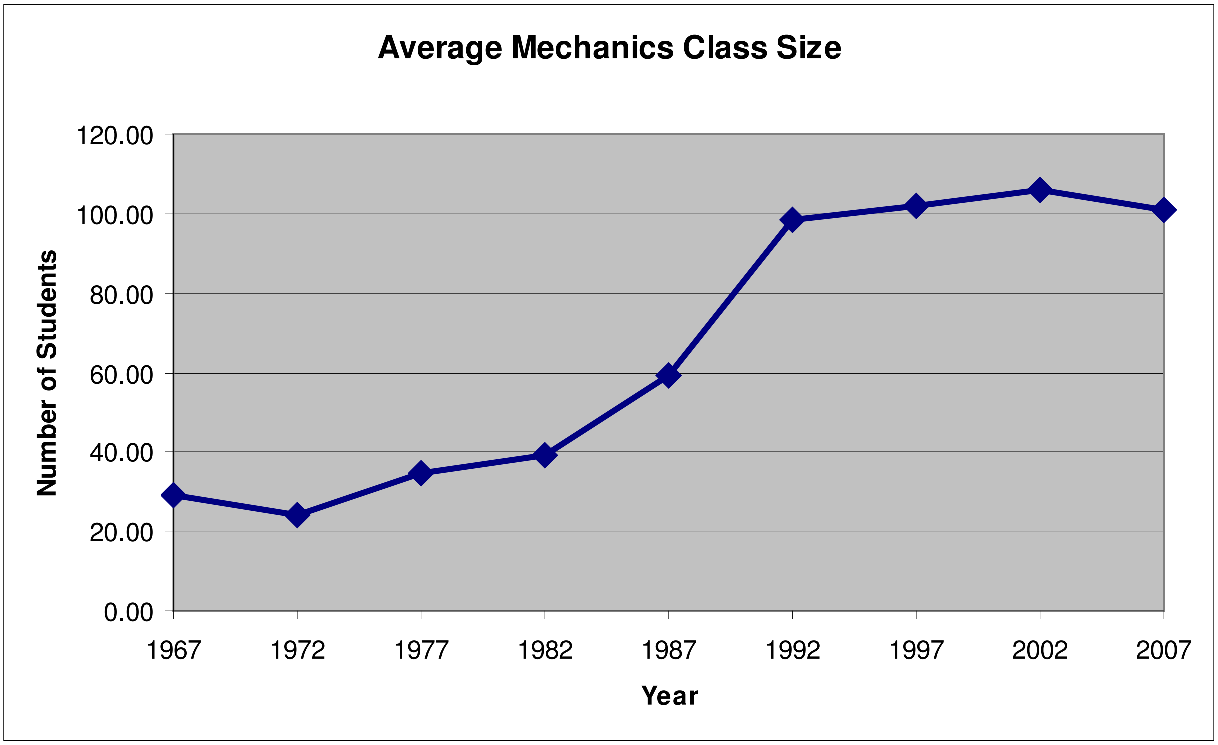

Figure 1: Five Year Enrollment Averages for Engineering Mechanics Courses

The Civil and Environmental Engineering Department administration responded with efforts to minimize multiple sections and to learn to effectively teach large sections of undergraduate engineering mechanics students. This has allowed the department to offer new faculty members several years with minimum teaching expectations (usually only one class per semester and never more than one new preparation) in order that they might develop a productive research program. Eventually increased faculty resources were provided but they have been accompanied by continually increasing research expectations. Thus the downward pressure on teaching loads has continued and the teaching of the undergraduate engineering mechanics series has continued to be the target for improved teaching productivity. Since the in-department and service teaching associated with these courses represents approximately one third of the total student credit hours taught by the entire department, increased efficiency in teaching these classes has the largest effect on average teaching loads.

The Engineering Mechanics Instructional Laboratory (EMIL)

When class sizes were small, tutoring of students and grading of homework and examinations was expected of the class instructor. As section size increased, this arrangement became unreasonable and the department began to allocate student teaching assistants. Initially, these teaching assistants provided limited tutoring (within specified time periods on certain days) and grading and recording of homework. As space was critical, the initial teaching assistants met students in less than ideal environments (usually in a materials testing laboratory). Encouraged by high ratings by the class members of the teaching assistants and the full utilization of the provided space, the department administration continually responded with increased space and the approval of requests for increased teaching assistant support. Finally, a large room was made available. Initially, this room was time shared with a few design classes which needed the large tables which came with the room. This arrangement proved somewhat awkward as homework was submitted and collected in the room and sometimes a lecture was interrupted by the coming and going of students wishing to submit or retrieve homework. Every time the space was increased or improved and/or the time period that teaching assistants were available was increased, the utilization of the facilities and the rating of the service provided also increased. It remained easy to demonstrate that the space provided had very high utilization and that the students highly valued the service provided.

The current location of the EMIL is spacious (1,150 square feet), carpeted (relatively quiet), with nice (relatively new) chairs and large desks, and conveniently located in the main engineering building. The "in" and "out" files for homework and return of the examinations for each class are also located in the laboratory. No classes are held in this room.

Each class is supported by six teaching assistants who provide tutoring services from 7:00 a.m. each week day until 6:00 p.m. on Mondays and Fridays, and until 8:00 p.m. on Tuesdays, Wednesdays, and Thursdays. The early closing on Monday is due to the campus wide scheduling of religious meetings and the early closing on Friday is because of the history of low utilization during this period of time. The laboratory is also fully staffed on Saturday from 9:00 a.m. until 1:00 p.m..

The peak demand for tutoring services is always the hour before class (when homework is due). When possible, two teaching assistants are assigned for that hour. Having six teaching assistants available makes it possible to meet this schedule with each tutor available in the laboratory approximately ten hours per week. Note: With less than five teaching assistants available, it is possible that some hours will not be covered because the teaching assistants (who are all full time students themselves) are all in classes at the same time. We have found that this condition is rare when five teaching assistants are available, and very rare when six teaching assistants are available.

Complete solutions for the homework problems are provided to the teaching assistants and they are expected to be familiar with the upcoming homework problems before coming on duty. Our experience is that the solutions provided by the text authors are too abbreviated and that our intent to instill skills for complete, professional, and correct solutions requires the instructors to work all of the assigned homework problems. Each teaching assistant has some responsibility for correcting homework. Each section of each class has a recorder that is responsible for the assignment of homework grading (to the teaching assistants assigned to the class) and recording of homework, quiz, and examination scores. Each section also has a grader (usually one of the more experienced teaching assistants) that is responsible for grading (under the supervision of the instructor) quizzes and mid-term examinations. These examination graders also serve as the first reviewers in the examination appeal process. If students are not satisfied with the result of this review, they may then seek redress from the instructor (which is rarely sought). On average, the teaching assistants work approximately fifteen hours a week. The graders normally work fifteen hours a week but have increased work requirements when they grade the three mid-term examinations. On average, they work approximately twenty hours per week. The final examination has ten multiple choice problems so as to provide some relief from the requirements of complete, professional, and correct presentations of three or four problems found on the mid-term examinations and to make it reasonable (with large sections) to meet the deadline for final grade submissions.

Our university has conventional Fall and Winter Semesters with the third Semester broken into two (Spring and Summer) eight week terms. Semester length classes are taught during the Spring and Summer Terms by having each class meet for two consecutive hours on class days. Spring and Summer Term classes are usually smaller and the department provides correspondingly fewer teaching assistance resources. In order to provide good coverage during the terms, each teaching assistant is given responsibility for tutoring all three classes. More time is allowed for them to become familiar with the increased number of homework problems (which is compounded by the fact that the classes are meeting at twice the normal pace). Nevertheless, student ratings of the teaching assistants during the terms are usually lower because the teaching assistants are unable to remember the details of the many homework problems under consideration on any given day.

Applications to become teaching assistants in the EMIL are collected about two weeks before the semester or term is to begin. Selections are made by the director of the laboratory (one of the class instructors) on the basis of performance by the candidates in the engineering mechanics classes and overall grade point averages. The director then assigns teaching assistants to the individual classes with the primary criteria being availability to cover all of the laboratory hours. If possible, the director tries to provide new class opportunities for returning teaching assistants. The teaching assistants typically report that tutoring a new class for a semester approximately doubles their comprehension of the class material. The learning curves for repeated semester have a much lower slope.

From among the selected teaching assistants, the director then recruits experienced persons to serve as the graders. A small salary increment is provided to the teaching assistants that accept this responsibility. In addition to the nine to ten hours per week spent tutoring, the teaching assistants spend an additional four to six hours per week correcting homework and becoming acquainted with the complete solutions to the homework problems. Typically, the percent of teaching assistants which are women exceeds the percent of the engineering student body that are women. Those applying for teaching assistant positions are invariably engineering students and the percent chosen from the Mechanical Engineering Department and the percent chosen from the Civil and Environmental Engineering Department is usually in line with the percent of the class students from these two departments.

Approximately two weeks before the final examinations, the students in each class are given an opportunity to rate the current teaching assistants in the categories of knowledge, explanations, attitude and courtesy, and an overall evaluation. They are also given an opportunity to write individual or group related comments. This data is tabulated for each teaching assistant and reviewed individually by the laboratory director and the teaching assistants. This information has proven useful in decisions of retention and to help remedy individual deficiencies. Interestingly, the ratings of the teaching assistants are invariably higher than the corresponding average ratings of the teaching faculty. Using a range from zero to ten, the average ratings during for Fall Semester 2006, Winter Semester 2007, and Fall Semester 2007 were 8.98 in knowledge, 8.78 in explanations, 9.23 in attitude and courtesy, and 8.99 for the overall evaluation. Typically, the Spring and Summer Term values are lower by about half a point. Usually the solicited comments are positive, but occasionally a student will report a negative experience (usually that they had to wait too long for a teaching assistant to be available). We have yet to receive a single complaint for using the teaching assistants to grade mid-term examinations. The high point of the semester or term, for the laboratory director, is meeting with the bright, service oriented, highly motivated engineering students that serve as teaching assistants.

Satisfaction with EMIL

During November of the 2007 Fall Semester, a questionnaire was developed with the aim of learning the level of usage and satisfaction with the operation of EMIL. The following was learned from this inquiry:

- 98% of the students responding to the questionnaire use EMIL and 79% use it either often or for every assignment.
- 97% rate the quality of the tutorial service either good or excellent, while 83% rate the availability of the service either good or excellent.
- 53% believe that at least two thirds of their learning results from the mentoring experience and approximately two thirds believe that at least one half of their learning is a result of the mentoring.
- Comparing with other instructional laboratories (with which they have had experience), 87% believe that the effectiveness of EMIL is either the best or in the top one third.
- While 95% say, at worst, it is a reasonable wait for service, 74% say the lab is, at least, somewhat crowded and 78% feel that the teaching assistant resource should be increased.
- 85% say the distribution of teaching assistance coverage (early mornings, just before classes, during the week days, during the evenings, and on the weekends) is about right.
- 97% say that the teaching assistants manage a good balance between not being helpful and doing too much of their homework. A most remarkable result.
- 99% say that a review of the exam file is the most important factor in preparing for the examinations. Also a remarkable result.
- While 90% believe the combination of class discussions and the lab is, at least, relatively effective, only 16% believe the combination is fully compatible and effective.

In addition, students were invited to provide suggestions for improving the EMIL operation. A total of 63 comments were received from the 243 students that filled out the questionnaire. The comments were in the following categories:

- Seventeen suggestions to increase the number of TA's during busy times.
- Fourteen compliments of the lab and the TA's and eight individual criticisms of the TA's.
- Ten complaints of the physical crowding of the lab.
- Eight suggestions to improve the lab procedures or physical facilities.
- Six suggestions or complaints about the class discussions.

Program Assessments for Mechanics Classes

The ability to understand fundamental engineering science is the specific ABET program outcome that is directly supported by material taught in engineering mechanics courses. A complete list of the program outcomes of the Bachelor of Science program in civil engineering at our university are:

1. Understand fundamental principles of mathematics and science.
2. Understand fundamental engineering science.
3. Understand geotechnical engineering.
4. Understand structural engineering.
5. Understand transportation engineering.
6. Understand water resources and environmental engineering.
7. Be able to design civil engineering systems and solve constrained problems with innovation.
8. Be able to use modern engineering tools, conduct experiments, and analyze uncertain data.
9. Be able to communicate ideas effectively, work in teams, and lead others.
10. Be familiar with professional practice, business management, and public administration.
11. Be aware of cultural, societal, contemporary, historical, global, and sustainability issues.
12. Be committed to life-long learning and service as licensed engineers of integrity and faith.

Department assessment of understanding fundamental engineering science (i.e. program outcome 2), includes 1) test scores on the FE exam, 2) student evaluation of the mechanics courses immediately after completing the class, and 3) student self satisfaction of competencies expressed in an exit interview at the time of graduation. Temporal data of these three assessments for the mechanics courses are presented next.

The FE exam is a primary direct measure available for comparing the technical competence of our students against the skills of engineering students nationwide. This exam is administered twice per year. Over ninety-five percent of our students register for and take this exam. They generally take it in their senior year. Figure 2 depicts the temporal trend in student performance for program outcome 2. Notice that this measure for our students is consistently above the national average.

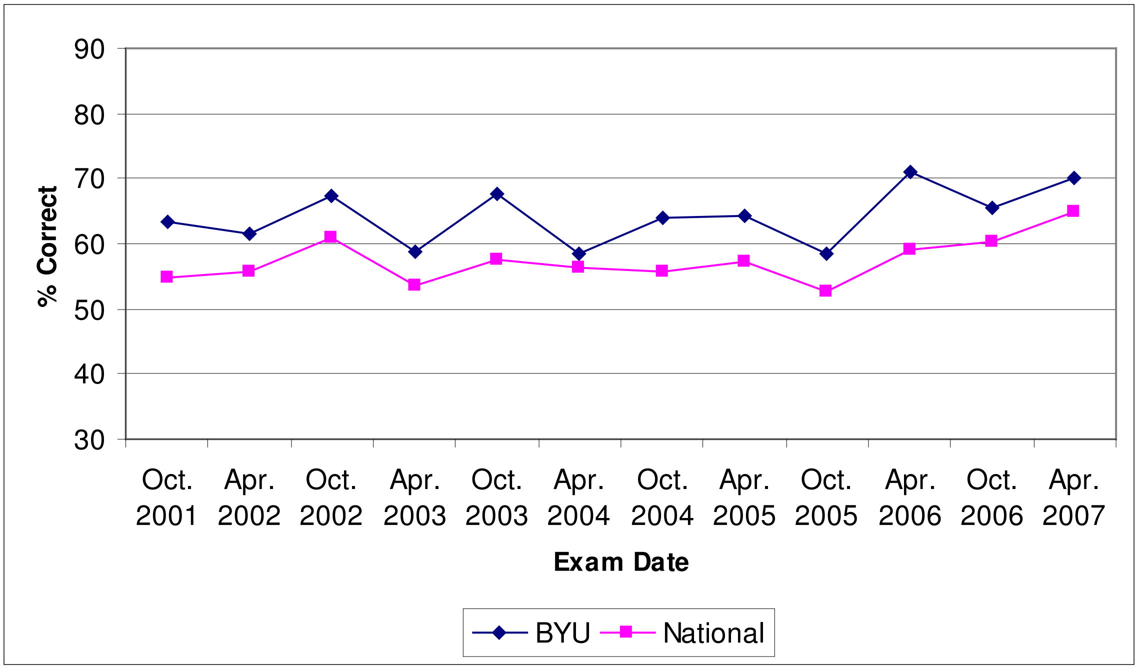

Figure 2. FE Exam Combined Scores in Statics, Dynamics, Strength of Materials and Engineering Mechanics (% Correct)

Student evaluations provide an indirect measure available to evaluate the confidence of students in their learning associated with individual courses. In our department, these evaluations are conducted at the conclusion of the specific class. The students provide written responses to a questionnaire survey that asks them to rate the development of each course competency according to the following scale: 1 (poor), 2 (fair), 3 (average), 4 (good), and 5 (excellent). For reporting purposes here, these values are then multiplied by 20 for evaluation on a 100-point scale. The composite student evaluation for the fundamental engineering science outcome is given in Figure 3. Figure 4 shows the average student evaluation of all program outcomes for the past six years. We note that this measure provides a very satisfactory assessment of student confidence in engineering fundamentals.

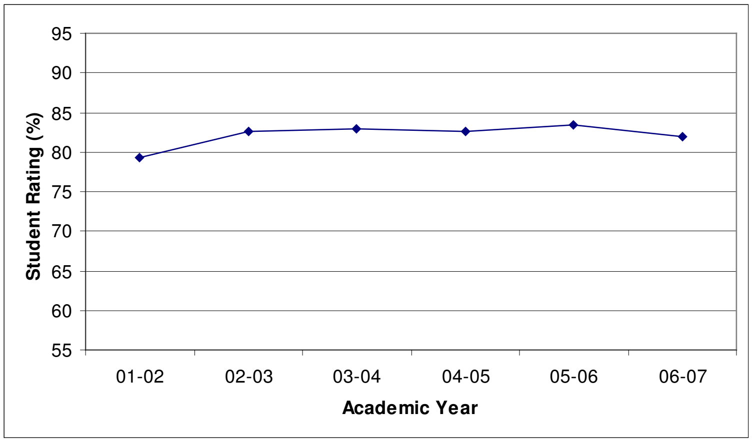

Figure 3. Scaled student evaluation of program outcome 2 – Understand fundamental engineering science. This measure is taken immediately upon completion of class.

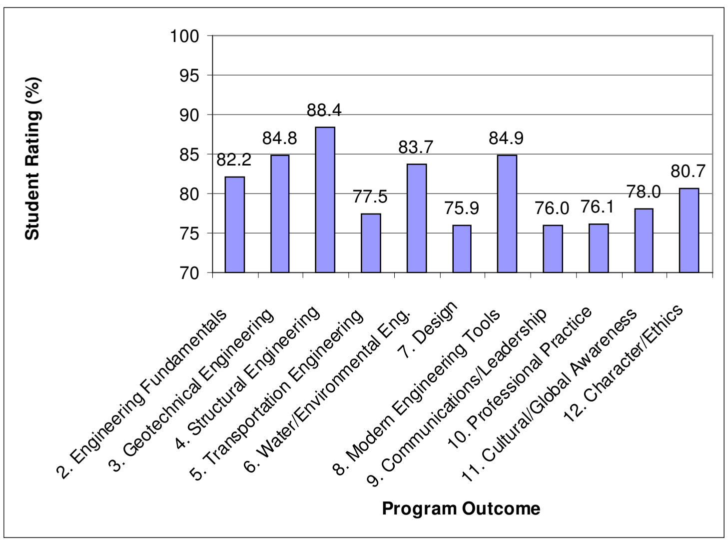

Figure 4. Comparison of 6 year average (2001-2007) of student evaluation of program outcomes. This measure is taken immediately upon completion of class.

Student exit interviews with the department chair provide another indirect measure available to evaluate the confidence of students in their learning at the conclusion of their undergraduate programs. Exit interviews are conducted of each graduating student by the department chair. These data are collected three times per year, corresponding to three graduation ceremonies, and then analyzed by academic year. The students provide written responses to a questionnaire survey that asks the students to rate on a scale of 1 (poor) to 10 (outstanding) how well the program enhanced their understanding and/or abilities in each area defined by the program outcomes. As explained earlier, these values are then multiplied by 10 for evaluation on a 100-point scale. The temporal data for the basic engineering science outcome is given in Figure 5. Figure 6 shows the average exit interview student rating of all program outcomes for the past six years. Note that satisfaction with the basic engineering science outcome rates very high.

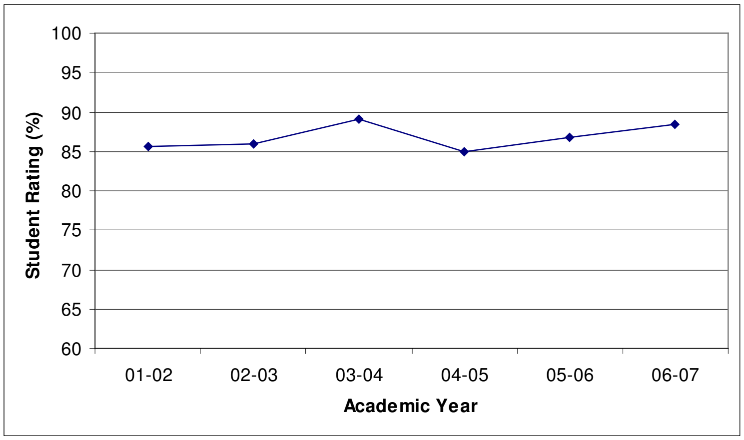

Figure 5. Scaled student evaluation of program outcome 2 – Understand fundamental engineering science. This measure is immediately prior to graduation in an exit interview with the department chair.

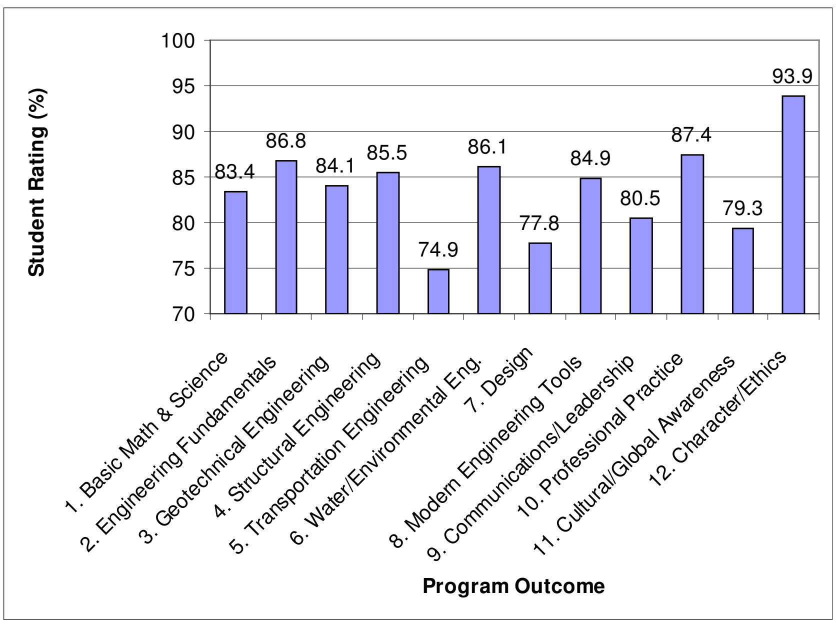

Figure 6. Comparison of 6 year average (2001-2007) of student evaluation of program outcomes. This measure is immediately prior to graduation in an exit interview with the department chair.

Discussion

The questionnaire verified that the laboratory is highly used and is an important component in teaching engineering mechanics subjects. It also confirms that the teaching assistants are providing a high quality and important service.

There is a level of concern about crowding and availability of teaching assistants during busy times. Part of the problem has been that other faculty have discovered the nice environment of EMIL and have assigned their own teaching assistants into this facility. While willing to share the resource, the department has requested that these faculty not schedule their teaching assistants into the lab during the busy times (just before class).

It is evident from the questionnaire and associated student evaluations of teaching that the students would like to see increased student-instructor interaction in class. This is relatively difficult in large classes but is being attempted.

It was unexpected to find that ninety-nine per cent of the students named "review of the exam file" as the most important factor in preparing for the mid-term examinations. Certainly, in a class that attempts to grade solution presentations as well as numerical answers, it is important to provide examples (including keys) of mid-term examinations that demonstrate the expected level of completeness and professionalism. While other classes may not have such a strong need of such examples, it is believed that extensive exam files would prove helpful in many university level class environments.

Conclusions

The primary conclusions of this paper are

1. Large numbers of undergraduate students can be effectively taught engineering mechanics subjects in an environment that includes the efficiency of traditional classroom instruction to large classes supplemented by a highly trained group of teaching assistants that interact with undergraduates in a mentored environment.
2. Department faculty resources can be optimized and effective education of mechanics principles can be achieved by reducing the number of faculty involved with classroom time and augmenting the faculty with high quality teaching assistants.
3. Students readily support the mode of education currently offered by the EMIL.
4. The savings in faculty salary is very significant. During a Fall or Winter Semester, the elementary engineering mechanics classes average nearly one hundred students per class. Our current average teaching expectation of approximately one and two thirds classes per faculty per semester assumes additional responsibilities like supervising undergraduate and graduate research assistants and otherwise developing a research program. The equivalent "teaching only" expectation is three classes. Thus, our program requires two full time faculty equivalents. If class size were to be reduced to thirty-three students so that the classes could reasonable be taught in a conventional manner, we would need eighteen sections or six full time faculty equivalents. Also, with one teaching assistant allocated to each regular section (our normal practice), there would be no savings in teaching assistant cost.

The assessment data used for ABET accreditation indicates that outcomes associated with the mechanics courses supported by EMIL are among the highest rated outcomes in the department. Thus, the process for teaching the elementary engineering mechanics courses has proven to be both cost effective and successful in meeting desired ABET outcomes.

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