# First-Year Experiences Implementing Minimum Self-Paced Mastery in a Freshman Engineering Problem-Solving Course

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## ABSTRACT

The objective of this paper is to introduce the reader to our experiences in teaching a freshman engineering problem-solving course using a modified form of mastery learning. A challenge in teaching engineering analysis to freshman students regards the relatively wide variance in their maturity and problem-solving skills. We decided to accommodate for this variance while ensuring a minimum level of competency at the completion of the course by implementing minimum self-paced mastery.

Two nontraditional concepts are utilized in this course: self-pacing and mastery. Self-pacing in its purest form allows students to complete their learning of the units of material at any time during the course. Minimum self-pacing requires that students complete their learning of the unit material within a specified window of time. Mastery requires that students demonstrate a minimum level of competency on a unit of material before moving ahead to subsequent units.

Various aspects of the course are covered. A description of course content and a detailed description of the minimum self-paced mastery technique are presented. Also presented are the impacts of this technique on student utilization of office hours, student utilization of collaborative study groups, student performance on exams, and student retention beyond this course.

## INTRODUCTION

For the past five years, the Department of Engineering at Baylor University has taught a course, EGR 1302 - Introduction to Engineering Fundamentals, to be taken nominally in the spring semester of the freshman year, and required of all engineering majors. The objective of this course is to develop and improve student analytical problem solving skills and therefore promote increased student retention through the sophomore course sequence of Statics, Dynamics, and Electric Circuit Theory. The course catalog description is as follows.

> "*Introduction to fundamental problem-solving techniques in engineering analysis of mechanical, electrical, computer and energy systems.*"

The course content, which has varied slightly depending on instructor(s), currently consists of three main topics: an introduction to statics, an introduction to electric circuit analysis, and development of the mathematical techniques associated with each. In the statics half of the course, the emphasis is on vector mathematics, units, force/moment definitions and resultants, and 2-D equilibrium. The circuits half of the course focuses on definition of dc circuit quantities, units, application of Ohm’s and Kirchhoff’s Laws, and a brief introduction to time varying voltage/current and complex numbers. Solution of simultaneous algebraic equations is an important topic throughout the course and we teach the use of the TI-85 calculator for simultaneous equation solution, vector math, and complex math.

Enrollment data from the first several years of the course suggest that it did not have a significant effect on the retention of engineering students through the sophomore year and into the junior year. The EGR 1302 course appeared to simply redistribute the overall attrition by filtering out many students earlier than might have been lost otherwise. The course was not well received by the students judging by student performance and attitude.

One big challenge in the course is dealing with the wide variance of maturity and skill across the freshman class. Among the many problems observed are: many well-prepared students become bored with the material, many under-prepared students are overwhelmed, and many capable students lack the maturity and discipline to practice and keep up with the homework. We found that success in the course did not correlate with student SAT scores. In fact, many high SAT students were doing poorly.

In spite of the disappointing results, we felt that the premise of having a course to promote the development of freshman student problem solving skills was still valid. In addition, we wanted to keep a course in the second semester of the freshman year to maintain contact between engineering majors and the engineering department. Consequently, we sought to develop a new strategy for delivering the course that would simultaneously satisfy to two apparently opposing requirements: that the course be very demanding of students to learn and practice problem solving; and, that the course have a high success rate and motivate, rather than weed out, students.

The following describes the technique we have implemented, Minimum Self-Paced Mastery. We have used this technique in the Spring and Fall semesters of 1997.

## MINIMUM SELF-PACED MASTERY

### *Rationale*

Two well-known, yet non-traditional, concepts are utilized in this course: self-pacing and mastery [1-4]. Self-pacing in its purest form allows students to complete their learning of the units of material at any time during the course. Minimum self-pacing requires that students complete their learning of a unit of material within a specified window of time. Mastery requires that students demonstrate a minimum level of competency on a unit of material before moving ahead to subsequent units. The student is allowed multiple opportunities to demonstrate mastery of a unit within the specified time window. There are serious consequences, explained below, for failure to master a unit in the specified time.

There were several hypotheses that served as the basis for adopting this approach in this course.

- The self-pacing should allow for the better-prepared students to work at a pace suitable to challenge them and prevent boredom.
- Mastery should ensure that every student who passes the course has achieved a minimum level of competency in all the course topics.
- Less-prepared students should benefit from the multiple opportunities to master the material.
- Small time windows for mastering individual units should serve to continuously provide the students with shorter term objectives that are very concrete and focused. This is based on our observations that in a traditionally structured course, many freshman fall severely behind due to lack of self-discipline and involvement in extracurricular activities. It is very easy for them to rationalize failing an early exam by convincing themselves they will make up for it later in the semester or on the final exam. Many lack the maturity to realize that this is unlikely without significant modification of their behavior.

*Implementation*

EGR 1302 is a three credit hour lecture course with the class meetings on MWF mornings. In addition, a two hour recitation session is scheduled in the afternoon on one day of the week. The students are given a syllabus that explains in detail the mastery grading system. The syllabus contains a calendar which schedules exam dates, lecture topics, and homework assignments for the entire semester. The textbooks which have been used for the course are Schaum's Outlines for mechanics and circuits. These were chosen because they contain large sets of solved and unsolved problems of a very fundamental nature.

In the Spring Semester of 1997 we divided the course into six units of material, three on mechanics and three on circuits. In the Fall of 1997 we changed to only five units of material, three on mechanics and two on circuits. Although we would have preferred to keep the number of units on each discipline balanced, we encountered scheduling difficulties with six units. It was much easier logistically to schedule five units into a fifteen week semester.

To be successful in the course, a student must master the material of each unit. Mastery is demonstrated by performance on *unit exams*. Unit exams fall into three categories.

- The *Main* unit exam for a unit is given during the recitation session in the week following the completion of all of the lectures for that unit. This is comparable to the timing of an examination in a traditionally structured course. Main unit exams are scheduled at three week intervals.
- *Accelerated* unit exams on a unit may be taken during the recitation session on any week prior to the week of the main unit exam for that unit, provided that all previous units have been mastered. Students taking accelerated unit exams will not yet have heard all of the lectures for that unit.
- *Post* unit exams for a unit can be taken during recitation in the two weeks following the main unit exam for that unit. A maximum of two post unit exams are allowed for any unit.

Two weeks after the main unit exam for a unit, the unit becomes closed. Only one exam can be taken in any week. There is no final exam.

Mastery of a unit is defined as scoring 70% or better on *any* unit exam for that unit. Once a student has achieved mastery on a unit, he or she may choose to continue to take exams on that unit (until it is closed) in order to improve his or her score. Alternately, the student may choose to begin taking exams on the next unit. For a student who has mastered every unit of material, his or her final average in the class is calculated as the average of the scores of the last attempted unit exam for each unit.

If a student fails to master any one unit of material, then the student will receive a grade of *D* in the course. If a student fails to master any two or more units of material, then the student will receive a grade of *F* in the course.

Under these rules, if a student scored 100 on each of four units and scored 60 on the remaining unit, which is an exam average of 92, the student will receive a *D* in the course. Another student who scores 70 on all five units, and consequently has a 70 average, will receive a *C* in the course. This example illustrates the emphasis placed on mastering all of the units of material. The students become very aware that their final course grades are on the line every three weeks.

*Administration of Exams*

The administration of examinations is a serious consideration in this course in light of the fact that the students are allowed to take multiple exams on each unit, typically taking one exam each week of the semester. Consequently, an examination technique is needed which is a valid tool for evaluating mastery of the material, which allows for rapid generation of new exams, and which lends itself to ease and quickness of grading (both from the standpoint of faculty workload and the need to provide students with rapid feedback).

We have developed an exam format which we apply consistently for all exams on all units of material. Each exam has ten (10) fundamental engineering problems. Each unit of material lasts three weeks, or nine class periods, so there is roughly a one-to-one correspondence between class lectures and exam problems. The problems on the exams are modeled directly upon problems in the problem sets of the texts. Next to each problem statement on the exam paper is an answer block in which to write the solution to the problem. Solutions written in the answer block are graded with no partial credit. In order for a solution to be scored as correct, the numerical value must be correct to three significant figures, the units must be given correctly, the sign must be correct, and any other necessary information, such as the location of a reference point, must be included. A student receives either a 0 or a 10 for each solution. Consequently, exam scores vary from 0 to 100 in increments of 10.

It takes us, on average, approximately two hours to generate one exam. Typically, we need to produce two exams per week since some students may be taking an accelerated exam on one unit at the same time other students are taking a post exam on the previous unit. The solution key is generated in approximately 15 minutes. To score an individual student’s exam requires about 30 seconds. For a class size of thirty students, all exams can be scored in fifteen to twenty minutes. This allows students to find out their scores and look at their exams within half an hour of the exam period. We have found that the additional workload required for generating so many exams is more than offset by the ease of grading the course.

To master a unit, a student must obtain and correctly report the solution to at least 7 out of 10 problems during a 50 minute exam period. To be successful in the course, a student must correctly work at least 35 out of 50 engineering fundamentals problems, distributed with at least seven correct on each unit. In the appendix, a sample mechanics exam and a sample circuits exam are shown.

Each exam given on a unit is intended to be comparable to the other exams given on that unit and is written independent of whether it is a main, accelerated, or post exam.

### *Feedback to Students*

Completed exams are permanently stored in the faculty office(s). We allow students access to their exams during office hours. They may "check out" and review any previously taken exam and the corresponding exam solution key. We adopted this approach for two reasons. We wanted to compile the exams for the purpose of collecting data for evaluating the self-paced mastery concept. More importantly, we wanted to draw the students into our offices during office hours and have them review mistakes made on exams in the presence of the instructor.

## FIRST YEAR OUTCOMES

### *Unit Examination Results*

The overall average number of exams taken during the semester was 14.4 exams per student. Given that 15 class-weeks of the semester were spread over 16 physical weeks due to holidays, and that the final exam period was used as an examination time, the maximum number of exam opportunities was 17. Thus, students were taking exams at almost every opportunity. Table 1 shows the average number of exams taken as a function of student grade. Students receiving *A*'s tended to require only one examination less than the overall average. The fewest number of exams taken by any individual student was seven and the maximum was 17.

| Grade | Avg. Exams per Student |
|---|---|
| A | 13.3 |
| B | 15.2 |
| C | 14.3 |
| D | 15.0 |
| F | 16.3 |

Table 1. Average Number of Exams per Student by Grade

A bigger difference between students at different grade levels was found by looking at what *type* of exams were being taken, rather than at how many. Figure 1 illustrates the average number of accelerated, main, and post unit exams taken as a function of grade received. Students earning *A*'s tended to be ahead of the lecture material, taking advantage of accelerated unit exams and finishing the unit on or before the main unit exam. Students receiving lower grades tended to be lagging behind, predominantly depending on post unit exams to master the material.

It is difficult to say at this point which is the cause and which is the effect. Did students perform better *because* they took advantage of accelerated unit exam opportunities?

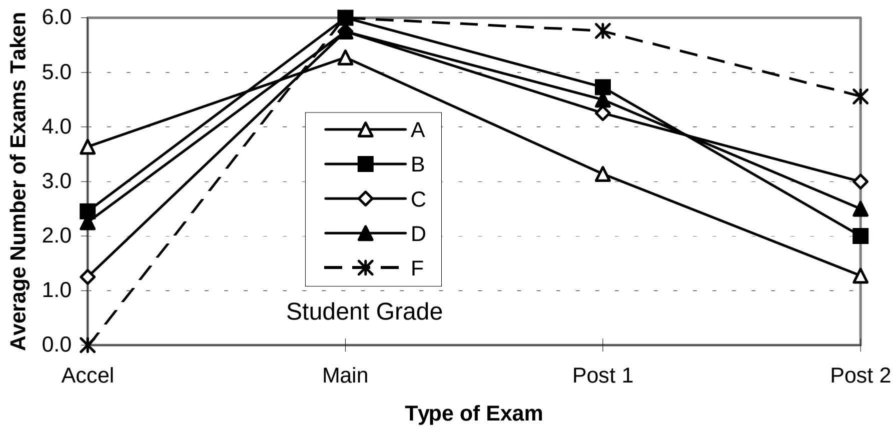



Figure 1. Number of Exams Taken by Type of Exam vs. Student Grade

<u>*Student Grades*</u>

During the first two semesters of this experiment, a combined total of 84 students enrolled in the course at the beginning of the semester. A total of 79 completed the course and were assigned a grade. Five failed to master an early unit of material and chose to withdraw from the course before the University's deadline for unconditional withdrawal.

Of the 79 students completing the course, the grades were distributed as shown in Table 2.

| Grade | No. Students | Percentage of Total |
|---|---|---|
| A | 30 | 38 % |
| B | 24 | 30 % |
| C | 6 | 8 % |
| D | 11 | 14 % |
| F | 7 | 9 % |

Table 2. Student Final Grades–1997

The results in Table 2 indicate that 76 % of the students were successful achieving a grade of *C* or better in the course, with 68 % at a level of *B* or better. Twenty three percent (23 %) were not successful in the course. In our program, a student may advance with a grade of *D*; however, that is highly discouraged since there are strict quality point requirements to remain in the program. If a student wishes to continue in engineering, they are advised to retake the course.

Grade data from spring semester 1996 (prior to modification of the course) are shown below in Table 3 for a class of 38 students.

| Grade | No. Students | Percentage of Total |
|---|---|---|
| A | 5 | 13 % |
| B | 8 | 21 % |
| C | 15 | 39 % |
| D | 3 | 8 % |
| F | 7 | 18 % |

Table 3. Student Final Grades–Spring 1996

The results in Table 2 indicate that 74 % of the students were successful achieving a grade of *C* or better in the course, with 34 % at a level of *B* or better. Twenty six percent (26 %) were not successful in the course. Thus, while the modified course significantly affected distribution within *A* to *C* range, percentages of successful students did not change appreciably.

*Problem Solving Practice and Skill Development*

We have identified one outcome of the examination technique that we believe makes a very beneficial contribution to the fundamental objective of the course: developing student problem solving skills. Students take an average of 14.4 exams during the semester. At ten problems per exam, that is an average of 144 problems *attempted* per student. The overall exam average score has been computed at 62. Therefore, on average, students have *correctly worked* a total of 89 fundamental engineering problems on exams alone during the course of the semester. This does not take into account any homework problems that they may have attempted or solved. The format of the course has forced students into problem solving practice and repetition.

In addition, we have found that students rely heavily on their previously taken exams in studying for subsequent exams. The majority of students come to the faculty office to rework their previous exams and correct mistakes made. We have found a high interest on the part of the student in "closing the loop" in this fashion on old exams. In this way the exams become a valuable instructional instrument as well as an assessment instrument.

The amount of homework attempted and completed by students varies greatly and we have no data to estimate a range or average. Homework is neither graded nor collected. For each class lecture, approximately 10-20 related homework problems in the text are identified in the syllabus. The hour-long recitation sessions provide an opportunity for students to work on homework either individually or in groups and to seek help from the instructor.

Another positive outcome we have observed is due to the no-partial-credit nature of the exams. Student attention paid to detail in their work and to correctly reporting answers has increased. Students develop the habit of rechecking their calculations as time permits. Many exam papers have notes students have written to remind themselves to check units. They appear to become keenly aware that a mistake in calculation or in writing the form of an answer can be the difference between mastering a unit or not.

We are pleased with the amount of problem solving practice we have observed and in the number of students mastering the material. The ultimate test of how effective this course is at developing student problem solving skills will be to evaluate student performance in subsequent courses and long term student retention.

*Student-Faculty Interaction*

As stated above, we have found that students rely heavily on previous exams as study tools. Because these exams are filed permanently in the faculty office(s), students have made heavy use of faculty office hours. This is true for virtually every student. Although we have not kept records of contact time with students outside of class, we can state conclusively that student use of faculty office hours in this course has been greater than in any other courses we have taught, and by a large margin. Students tend to come in groups to the faculty office to review their previous exams. They typically discuss problems within the group, help each other within the group, and consult with the instructor as needed.

The nature of this course appears to have had an effect on both student relationships with each other and with the faculty. We have observed that the students have readily formed loose and shifting study groups with whom they work in recitation, in the faculty offices, and apparently out of the building as well. They also freely share their exam scores, even extremely low ones, with one another. When reviewing previous exams they pass their own around among the group without hesitation.

The objective standard eliminates student competition for position on a grading curve. Retaking of exams diffuses the pressure of taking an exam. We feel that these factors contribute to what is almost a communal feeling among the students. In our opinion, these factors also contribute to a unique student-faculty relationship. They appear to relate to us more as a coach than as an adversary who is responsible for assigning their grades. Common complaints, such as complaints about the fairness of grading, complaints about the fairness of problems on exams, excuses for poor performance on exams, complaints that we did not give them sufficient information or sufficient lead time, and so on, have been non-existent. We make it clear at the beginning of the semester that the syllabus contains all of the information necessary for the student to know where they stand and what they have to do at all times. We emphasize to the students that the faculty will do whatever we can, in class and out, to help the student be successful. Overall, we feel this course has fostered a very positive and cooperative relationship between students and faculty.

The student-faculty relationship does change dramatically, however, when a student fails to master a unit, or units, and is facing a *D* or *F* in the course. This often happens early or in the middle of the semester. If it is early enough, then we advise the student to withdraw from the course without any effect on the student’s transcript. If it is past the deadline for unconditional withdrawal, then the student is committed to a grade of *D* or *F*. There have been two diametrically opposed student reactions to this circumstance. Some students apparently accept what has happened and continue on with a *D* or stop attending class with an *F*. A few students have engaged in lengthy discussions with the faculty concerning the grading policy. These students have felt very frustrated that their grade has already been determined before the end of the semester and that there is no amount of work they can do to reverse that. A modification to the grading scheme to be implemented in spring 1998 is to allow a student who has failed to master one unit of material a final attempt to master that unit at the end of the semester.

*Student Retention Beyond This Course*

Students normally take Statics the semester immediately following this course. As a preliminary method of estimating the effect of the mastery technique on student retention, we have determined the number of EGR 1302 students who in the subsequent semester have successfully completed Statics with a grade of *C* or better. We have compared the data from the first semester of mastery with that from the previous four years in which EGR 1302 was taught traditionally. Table 4a indicates the numbers and percentages of *all* students in EGR 1302 retained through Statics prior to and after mastery. There was a 14% increase in the number of students retained.

One concern that helped lead to the development of the mastery course was the number of high SAT students that were being lost. Therefore we have recalculated the retention rate for those students who have math SAT scores of 600 or greater. Only data from the year before mastery and the year with mastery are shown. The results are shown in Table 4b. When just the high SAT students are considered, there was a 24% increase in the number of students retained. Strikingly, in the year prior to mastery, high SAT students were retained at a rate lower than the overall population rate. With mastery, the retention rate of high SAT students is comparable to that of the overall population.

These results are based on a limited sample from one semester of EGR 1302 and the subsequent semester of Statics. We plan to continue to track these two groups of students as well as future groups.

| ***All Students*** | **EGR 1302 Enrollment** | **Students making ≥C in Statics** | **% Retained ≥C Students** |
|---|---|---|---|
| Traditionally taught<br>Intro to Engr. Fundamentals | 228 | 112 | 49% |
| Minimum Self-Paced Mastery<br>Intro to Engr. Fundamentals | 51 | 32 | 63% |

Table 4a. Comparison of Overall Retention Rates Before and After Mastery

| ***Students with ≥600 Math SAT Scores*** | **EGR 1302 Enrollment** | **Students making ≥C in Statics** | **% Retained ≥C Students** |
|---|---|---|---|
| Traditionally taught<br>Intro to Engr. Fundamentals | 33 | 14 | 42% |
| Minimum Self-Paced Mastery<br>Intro to Engr. Fundamentals | 32 | 21 | 66% |

Table 4b. Comparison of Retention Rates Among Students with ≥600 Math SAT Scores Before and After Mastery

## REFERENCES


1. Guskey, T. R., Implementing Mastery Learning, Wadsworth, 1997.

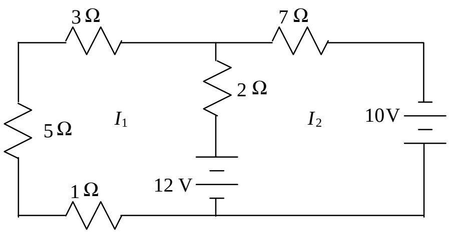
2. Wankat, P. C. and Oreovicz, F. S., Teaching Engineering, McGraw-Hill, 1992.

3. Kulik, C.L.C., Kulik, J.A., and Bangert-Drowns, R. “Effectiveness of Mastery Learning Programs: A Meta-Analysis,” *Review of Educational Research 60*(2), 1990.

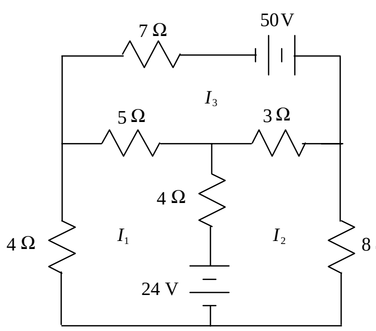
4. Guskey, T.R. and Pigott, T.D., “Research on Group-Based Mastery Learning Programs: A Meta-Analysis,” *Journal of Educational Research 81*(4), 1988.


## APPENDIX: SAMPLE CIRCUITS AND STATICS EXAMS

1. Find the mesh current $I_2$ in the circuit shown.



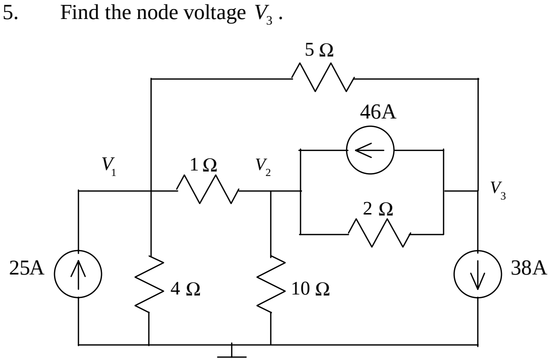

2. Find the mesh current $I_3$ in the circuit shown.



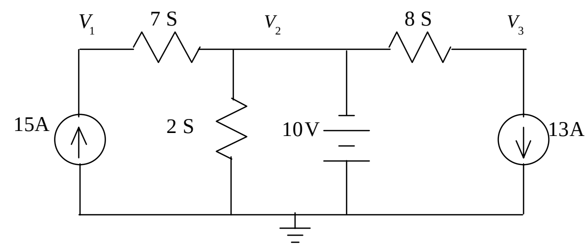

3. Find the expression for a 300 Hz voltage sine wave that has an effective value of 45 V.

4. Find $(6.8 + j9.2)^2(23.4\angle 25^\circ)$ in rectangular form.

5. Find the node voltage $V_3$.

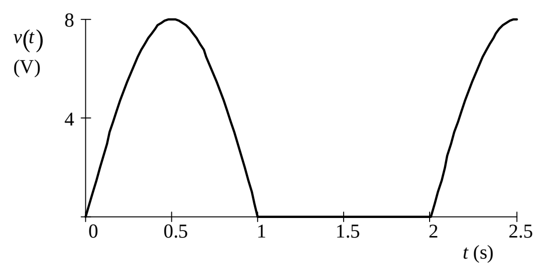



6. Find the node voltage $V_2$.

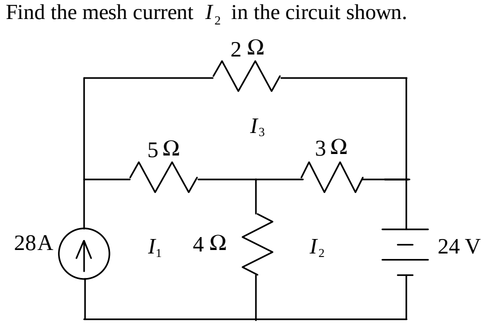



7. Find the radian frequency of a sinusoidal current that has a period of 25 μs.

8. Find the average value of a half-wave rectified sinusoidal voltage that has a peak of 8 V. This wave consists only of the positive half-cycles of the sinusoidal voltage. It is zero during the times that the sinusoidal is negative.

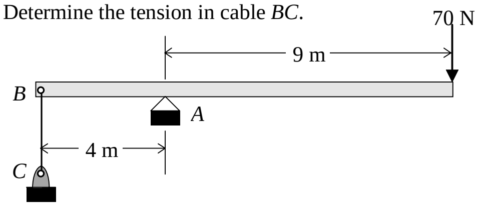



9. Find the mesh current $I_2$ in the circuit shown.

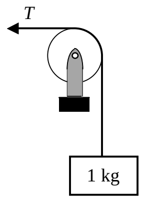



10. Find the current corresponding to $\bar{\mathbf{I}} = 9.6\angle -15^\circ$ A that has a radian frequency of 314 rad/s.

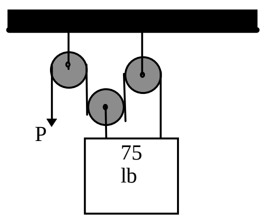
1. Determine the tension in cable *BC*.



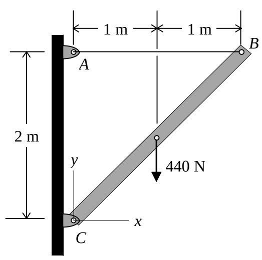

2. Determine the force *T* for equilibrium of the system.



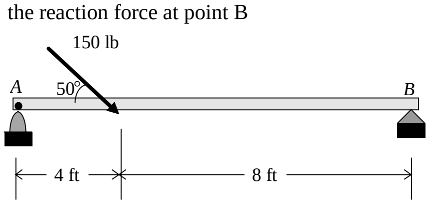

3. Determine the force P required to hold the 75 lb block in equilibrium utilizing the pulley system shown.



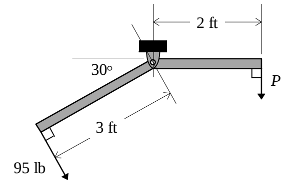

4. Determine the pin reaction at support *C*.



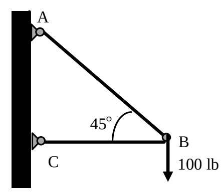

5. The beam is pinned at A and rests on a point at B. Determine the reaction force at point B



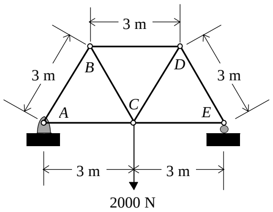

6. Find the force *P* to maintain the bell crank shown below in equilibrium.



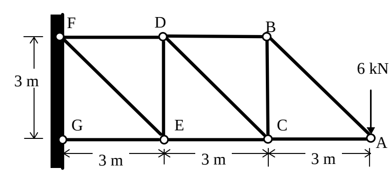

7. Determine the force in member *AB* of the truss shown below.



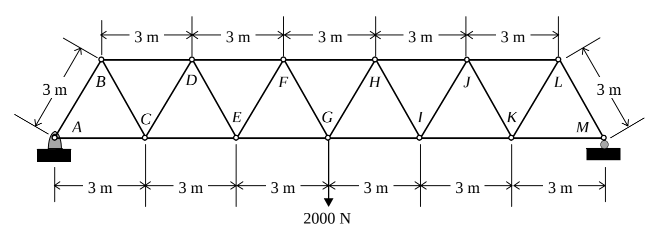

8. In the truss shown below, determine the force in member *AB*.




9. Determine the force in member *DB*.




10. In the truss shown below, determine the force in member DF.



define what the course is

separate the course from the technique.

Parag. Describing the course

define the grading scheme

define how to implement exams and score exams (n.p.c.)

statistical results compare SAT and exam scores across two semesters

number of problems worked by students compared to non-mastery students

failure becomes an unacceptable mode of operation