

How to Use Technology For Teaching Problem Solving In Effective and Efficient Ways

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Effective and efficient methods of teaching problem-solving using interactive computer courseware have been developed as a result of more than 20 years of experimentation with courseware development and implementation in classes at several universities. This presentation deals with Statics and Engineering Mechanics courses for architecture and engineering students. Problem-solving courseware combining instructions and computer-graded tests was initially developed on the NovaNET¹ system. The cT 3.00² authoring language was used for more recent development. A CD with ten programs in cT 3.00 for Statics course will be demonstrated (Figure 1). For development of Web-based homeworks and quizzes Mallard³ authoring web-based software was used. The paper describes in detail features of effective and efficient problem-solving programs. Observed advantages and disadvantages of different ways of material presentations, teaching and testing are explained. Students' evaluation of courseware for many years is presented.

Problem-solving courseware in engineering is a necessity in the era of information explosion. Engineering education heavily depends on students' ability to apply theory to practice. Teaching problem solving and design requires a lot of faculty time for checking and grading individual works of many students. Finding effective ways of using the latest developments in computer technology for this purpose has been my goal for many years. Interactive problem-solving programs in Mechanics were tested and used at the School of Architecture and at the Theoretical and Applied Mechanics Department at UIUC as well as at Engineering Schools in Alabama A& M University at Normal, Alabama (AAMU) and Southern Illinois University at Edwardsville (SIUE). The development was partially sponsored by several grants from NSF. AAMU and SIUE were coinvestigators in the sponsored projects.

Learner-Tailored Teaching Method for Problem Solving

Observing significant differences in students' comprehension of the same concept and ability to apply theory to solving practical problems, one comes to the conclusion that the best way of teaching problem solving to an individual student can be found only experimentally⁴. An interactive computer program may produce an educational environment where the implementation of this approach becomes feasible.

The best results in grades and in students' evaluation of the programs were achieved when the topic and related problems were first explained and then tested in an interactive step-by-step fashion. This approach allows a question-specific feedback each time student's response is wrong. In addition the correct answer can be provided after certain number of wrong answers while no points will be assigned for this question.

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In the end the student will know not only answers but also the correct ways to start and to go on with the solution.

An important feature of computer based homework assignments can be a provision for improving the initial grade. Students are allowed to work in the same program on the newly generated problem covering the same topic but completely different from the initial problem in its sketch and numerical data (Figure 2). In doing so they use their experience learned from their own mistakes made in the first attempt.

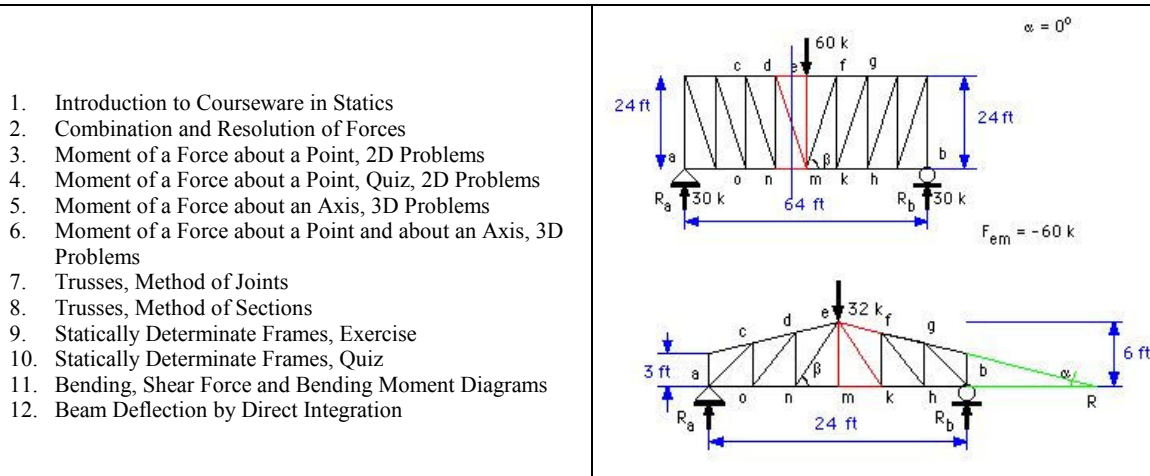


Figure 1. List of computer-graded interactive lessons with homework problems to be solved on computer screen in a step-by-step fashion. New problems are generated at each execution of the program.

Figure 2. Examples of two versions of trusses appearing in the same assignment for finding internal forces in truss members shown in red color using the method of sections.

Quiz Problem 2. Draw shear force and bending moment diagrams for the beam in the sketch. All force values are in kN, all the distances are in m.

To find reactions at support A and B, you may choose to write values for R_a and R_b , or go through equilibrium equations step by step. Type 1 or 2 at the arrow.

- 1) Enter values for R_a and R_b
- 2) Go through equilibrium equations

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Figure 3. Example of giving students the choice of fast or slow movement in the problem solution.

Accommodating a Diversified Pool of Users

The following problem solving techniques proved to be effective in providing challenge to a diversity of users without discarding slow learners:

1. Free back and forth movement from one test problem to another.
2. Program generated new data each time a student works on any exercise or test problem which helps making practice attractive and challenging even for fast learners (Figure 2).
3. Choice between an elaborate step-by-step solution and do-it-yourself approach with typing in only the final results (Figure 3).
4. Hints after each wrong answer, and a correct answer given after three wrong ones. The grade is reduced drastically with the number of tries required to get the correct answer.
5. Help message containing general rules and topic related formulae provided only upon request.
6. Option of working on an extra exercise problem different from the previously solved problem but sufficiently similar to be able to learn from previous mistakes.
7. Providing extra explanations at the crucial points of the solution presented in the exercise problems.
8. Questions designed to provoke students' thinking on strategy applicable to the problem solving process (Figure 4). This is rarely done in computer-based problems.
9. Incorporating graphical interpretations of important concepts in problems explanations and solutions (Figure 5)
10. Questions encouraging correct assumptions of directions of unknown reactions (Figure 6). This stimulates thinking prior to making any assumptions.

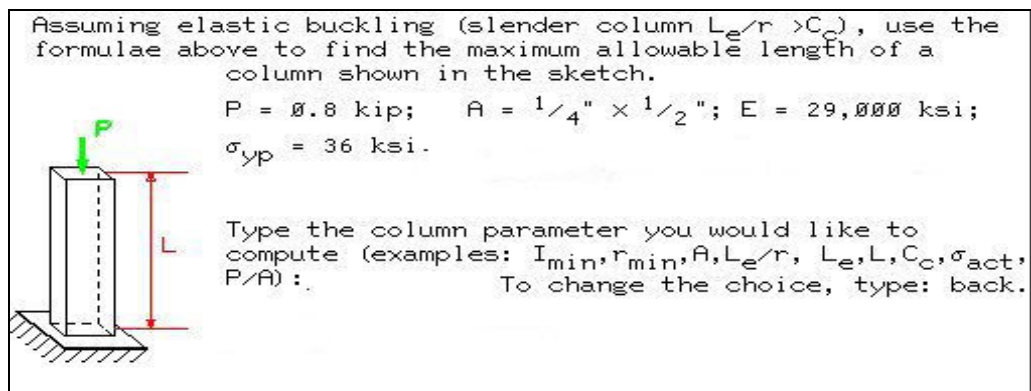


Figure 4. Example of a strategy-oriented question

Students get completely shocked when seeing such an unusual question as shown in Figure 4. Not being used to think out the strategy of the solution they almost always make a wrong choice in the beginning and have to be explained why it is wrong.

Using graphical interpretation in problem solving is shown in Figure 5. The problem dealing with the state of stress at a point is stated as shown in the left column. The numerical and graphical data are generated anew at each execution time. The program creates coordinate system $\sigma - \tau$ for the Mohr's circle and its graph. Students have to

answer questions about the location of points representing stresses on the vertical and horizontal planes and the center of the circle. Then they have to calculate the radius of the circle, and after this the program provides the picture of it. The students have to identify the Pole of Planes, calculate the principal stresses and indicate their directions using the Mohr's circle.

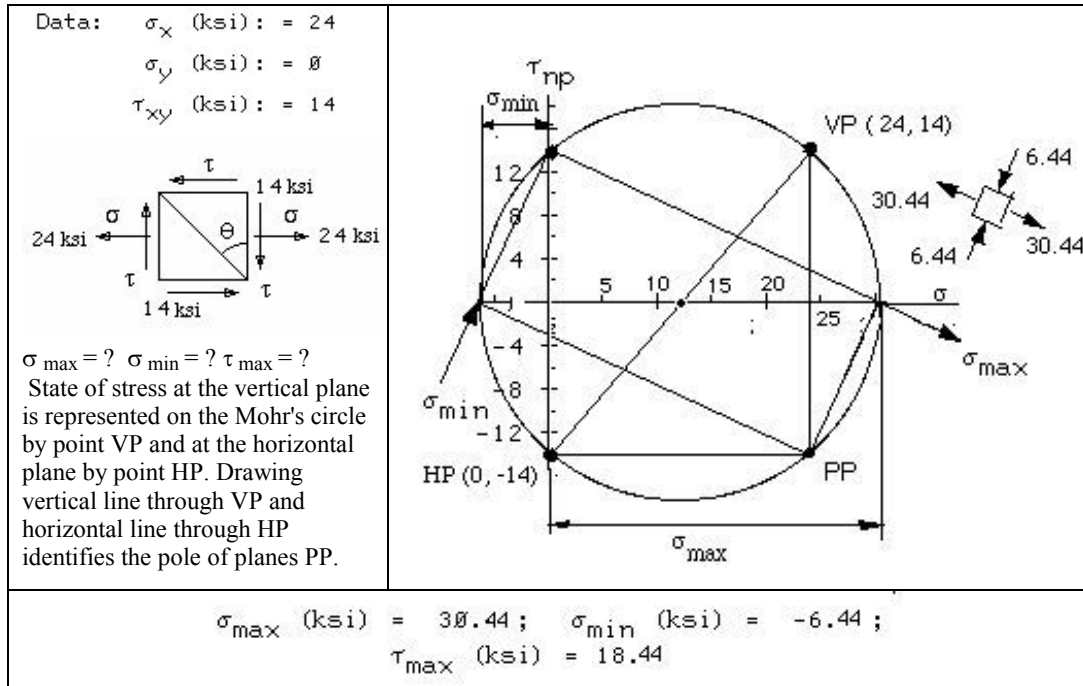


Figure 5. Using program-generated data-dependent coordinate system for asking students to determine principal stresses and their directions using the Mohr's circle.

Exercise Problem

Try to estimate correctly the directions of vertical and horizontal components of the reactions. Imagine how the supports would move under action of the load, if they are allowed to move. The reactions oppose the tendency to move.

Member BC.
 Assume the directions of vertical (V) and horizontal (H) components of the reaction at the pin indicated by the subscript. Depending on your choice, type + or - at the arrow.

$H_B = \gg$

"+" means: for V \uparrow , for H \rightarrow
 "-" means: for V \downarrow , for H \leftarrow

Press any key to continue.

Figure 6. Question requiring understanding of the ways structure works.

Students are encouraged but not required to make the right choice of the directions for unknown reactions. If after calculating these reactions the result comes out positive they get praise but they are not punished for choosing the wrong direction.

Comparison of two authoring software: cT-3.00 and Mallard

The structure of the quiz design software in Web-based Mallard does not allow judging of step-by-step questions in problem solution procedures. All the problems and questions are presented on one display and judged after all the answers are put in place. This type of final display has two significant disadvantages.

First, in this case the grading is reduced to all-or-nothing result without considering solution parts that could have been done correctly. To imitate the step-by-step solution procedure in Mallard questions each step can be presented as a separate problem⁵. Each of the problems in the sequence has similar but not identical sketch and numerical data. Each next problem has the previous steps answers incorporated into new data. For example, a problem of finding principal axes for a given area can be divided into 3 problems. First problem deals with locating the centroid for a given coordinate system for first data set. Second one asks to calculate the moments of inertia for similar problem with given centroid location. Third problem requires to find the principal axes for a third different area with given data for parameters that were questioned in previous problems.

Another disadvantage of Mallard is availability of the entire test for print out with all problems and answers being already judged. It is easy to use this printout for cheating, especially when the problems were given for homework assignments. Although each problem may have several versions presented at random there are many more students than versions. Observing the data for time spent in the assignment revealed unbelievable short time spent by some students. When confronted with the question about it, the students explained that they first printed out the assignment statement, then solved the problems by hand without dealing with computer and finally just typed in their answers.

The cT-3.00 software allows developing of an algorithm for generating new problem data and data-related sketch at each execution of the program. On the Web a new data and a new sketch come from a database incorporated in the program. A sophisticated judgment of students' inputs of alpha-numeric expressions for answers is possible in the cT program but not on Mallard. In case of the step-by-step presentation of questions and evaluation of answers, at no time the entire solution is seen on the screen. As a result it is not possible to print out all the answers on one sheet of paper. Considering all the above-mentioned features of the cT-3.00 courseware and actual observation of students' records, cheating was not a usable option even in homework assignments.

The advantages of Mallard are relatively simple programming and less time-consuming execution. It was found convenient to use Mallard quizzes for allowing students to improve their grades before finals. In this case the work had to be done in the presence of instructor and only one attempt was allowed. The Mallard allows several types of questions: multiple choice, numerical answer incorporating indicated tolerance, matching elements of two sets. This type of courseware can be successfully used only in class in the presence of instructor or teaching assistant.

The data in the tables shown in Figure 7 illustrate how time invested by students in computer-based homework assignments of the type described above can significantly improve their grades and stimulate learning. Students would not be able to invest this time without any feedback provided by sophisticated computer program that stimulates them to improve their performance. The data shows that given an opportunity to improve their performance, A-students have invested much more time in problem solving than B-students.

Arch 251 (4 lessons in a homework assignment)					TAM 151 (10 lessons in a homework assignment)				
Course Grade	Time spent on computer (hours/student)/(hours/lesson)			Number of students	Course Grade	Time spent on computer (hours/student) / NL*			Number of students
	Min	Max	Average			Min	Max	Average	
A	4.4/1.1	19.3/4.8	10.3/2.6	12	A	5.7 / 8	21.1/ 10	9.7 / 8.4	8
B	2.7/0.7	11.9/3	7.2/1.8	12	B	1.4 / 2	12.8 / 8	8.2 / 7.1	7
C	3.5/0.9	16.2/4	8.5/2.1	12	C	6.3 / 6	37.8 /10	15.4 / 7	3
D	5.4	5.4	5.4	1	D	7.7 / 8	8.4 / 7	8.1 / 7.5	2
					E	2.2 / 3	9.9 / 8	5.8 / 5.3	3

* NL is the number of lessons completed by the student who got this grade.

Figure 7. Comparison of Architecture and Engineering students' performance in Statics computer lessons and the relationships between the time spent on computer and the final score for each student.

Students' Evaluation of Computer Lessons in Statics

The following students' remarks were collected for several years from 1983 to 1998 by attaching an evaluation questionnaire to each lesson. There were five multiple choice questions and one open ended question where each student was asked to indicate what he or she liked or disliked in this lesson. A visiting professor from Sri Lanka was using the lessons in Theoretical and Applied Mechanics Department in Fall 1984 when only NovaNET³ version was available. Later most of the NovaNet lessons were converted to the cT 3.00 version although the NovaNet is still available at UIUC.

General Positive Remarks:

Using this method Statics could easily be taught to anyone and it makes it fun to learn.
The information is given in a logical, orderly fashion making it easy to follow along.
I like reinforcement again and again of basic ideas.
It calls for participation and so you know whether or not you understand the material. It makes a change from just reading from a textbook.
I like the way I got to work on problems and see if my answer was right or wrong. I think this lesson was very helpful.
Keep NovaNET for TAM 152. I feel like its the only way I'll learn something!
I liked the need for participation.

I think our four weekly hours of lecture should be skipped and spent here; I got much more out of this than I ever did from lecture.
I felt that the material covered in this lesson was very helpful in the manner it was presented in the NovaNET lab. It would help to do more.
It explains clearly, good diagrams. Can go over parts that you do not understand.
The lesson is self taught and you are forced to get the answer correct or at least see the correct answer and determine how the answer was obtained.
The lessons are much more interesting and easier to understand on NovaNET than the lectures.
Because the lesson was a step by step process, it made it a lot easier to understand and remember the lesson. It is a very good tool for learning.
The best feature is the moving illustrations.
I like choice of steps to begin with, the help button, like that it tells you what is wrong at each step, and tells if there was a better method than what you picked.
The best features of NovaNET are the graphics and the optional explanations.
The help mode was definitely a necessary element.
The methods are presented step by step to aid in learning, provides help if needed, and gives the student a choice of steps.
I felt the lesson explained the parallelogram very well and did a good job of using the law of sines.
The book does not ask continual questions, but NovaNET does. This helps with learning.
Using NovaNET clears up certain aspects of Statics problems by explaining the solution. Particularly, I now understand compression and tension by force.

Comments Advising Changes (Appropriate corrections were made.)

Announce the quiz in the beginning of it, because I did not have any idea that that was a quiz until I saw it graded.
I like the idea of using NovaNET, but I have difficulty not using pencil and paper in front of me.
Did not understand the question, "write the expression for ..." Need to see an example.
The examples are good and simple (easy to solve), but the answers required were not always clearly stated as to what they demanded.
There should be an initial recommendation to the user to take notes during the information portion of the lesson to allow a better chance on a test.
Use of cursor is helpful, thoroughness of topic is good, some screens advance to quickly to read.
I like printed material because it is much easier to go back and check information quickly and return to where you left off.
Like that one can travel at his own speed, good graphics. Dislike that some directions were confusing, need more detailed help available.

Conclusion

Efficiency in using new technology for teaching and learning can be achieved only if we explore new opportunities and develop teaching methods that will take full advantage of

unique features specific to computer environment. New methods can evolve as we try to incorporate new ideas in courseware, which is then used in a classroom. The feedback from the students and faculty provides evaluation of the courseware and ideas on its improvement. The sophistication of the lessons described here and in the publications⁵⁻⁹ can be fully appreciated only after trying them on NovaNet or on CD "Basic Statics".

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Helen Kuznetsov is a Research Associate Professor Emerita in the Structures Division of the School of Architecture at the University of Illinois at Urbana-Champaign (UIUC) where she was teaching for the last twenty years. All this time she was involved in developing, testing and implementing in her classes a variety of computer-based courseware. She got involved in developing computer-based courseware in 1982 when she worked at Computer-Education Research Laboratory at UIUC where the PLATO system was developed. Later the PLATO evolved into the NovaNET system¹. Helen Kuznetsov also authored a package of lessons and simulations on Road Design and Constructions for US Army Engineering School. These lessons as well as NovaNET lessons in Statics and Strength of Materials for Engineering and Architecture students are available on the NovaNET system now being delivered by Pearson Digital Company. Architecture students usually had 10 computer-based homework assignments per semester using the cT 3.0 interactive computer-graded lessons available on the servers of the computer laboratories of the UIUC and on CD "Basic Statics". In addition they had homework assignments and quizzes on Internet-based Mallard system where there are 12 problem-solving assignments in Mechanics of Materials and 13 assignments in Statics. Prior to coming to UIUC, Helen Kuznetsov was teaching at the Ohio State University in Engineering Mechanics Department. She published more than 20 papers in professional journals and proceedings of ASEE annual conferences. She continues her work on developing new courseware and improving the existing one.