Computer Technology for Enhancing Teaching and Learning Modules of Engineering Mechanics

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ABSTRACT: Improving the quality of learning and teaching has always been in the interest of instructors in all fields of study. There have been tremendous efforts to this end. In this article, learning and teaching modules enhanced with computer technology are introduced. This approach is based on concept questioning and scenario building aided with interactive animation, simulation, and rich graphical content. Modules for the engineering mechanics course covering fundamental topics in Statics, Strength of Materials, and Dynamics are prepared by using the proposed approach. Some examples of the prepared modules are presented. Design of the course module and its evaluation from student’s perspective are discussed. Based on evaluations using questionnaires by the students it can be inferred that this approach to teaching and learning helps students to increase their capacity to understand and instructors to convey their ideas more conveniently. © 2009 Wiley Periodicals, Inc. Comput Appl Eng Educ; Published online in Wiley InterScience (www.interscience.wiley.com); DOI 10.1002/cae.20321

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INTRODUCTION

In general, most students in science and engineering disciplines have difficulty in understanding fundamental concepts and basic principles. One reason for this deficiency in student learning may be that the classical lecture-mode of teaching by itself is not sufficient for students to grasp basic concepts. The learning style of students may vary in many different ways such as seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorizing and visualizing and drawing analogies; and building mathematical models. The teaching methods of instructors also vary from one another. Some instructors like to lecture, others demonstrate or discuss; one may focus on principles and other on applications; some may emphasize memorizing and
others may give more attention for understanding [1–4]. As a result of these variations in the learning styles of students and the teaching styles of instructors, a great amount of research effort has been put forward to address this issue in education. Carrier [5] reported that one of the important suggestions of this growing literature is that learning and teaching strategies should carefully analyze the need of students in the sense of instructor’s goals and course content. Teaching and learning strategies based on multiple technologies can be integrated in course content in order to provide the most effective learning and teaching.

As computers have moved from laboratories to classrooms and homes, much research has investigated their use for educational purposes. Since computer software can be a potentially powerful tool, it is important to find out which techniques are best, and subsequently employ these techniques to enhance the learning experience. In particular, computers can be used for a variety of multimedia techniques, and it is important to characterize the circumstances of their successful use. The use of electronic media has been widely recognized as an effective and efficient tool in delivering course materials [6–8]. Through interactive and visual appealing electronic media such as texts, animations, graphics, simulations and sounds, the teaching of key, and difficult to understand concepts in engineering education can be enhanced drastically.

The remarkable growth of web and other computer network technologies has added a large number of potential tools to the engineering education [9,10]. The trend in utilizing interactive and electronic media in presenting engineering principles has been increasing over the past few years. It has evolved from a resource only available to a minority, to an integral part of the public and private life. This affected, in a positive sense, the way people teach and learn. Some of the web-based course modules presently available on the web include fundamental engineering courses such as Statics and Structural Mechanics [2,11–18], Dynamics [19–22] and Thermodynamics [23–25], Virtualized laboratories for Earthquake Engineering [26], and Fluid mechanics [27] have been developed. There are supplemental modules, such as the award winning MDSolids and MecMovies by Philpot [28]. However, there has been less research into the use of animation in a classroom setting, because the skills and equipment required were scarce in the early days of computers. Early research compared graphics to text-only instruction. For example, Baek and Layn [29] compared the learning experiences of text-only, text plus graphics, and text plus animation instructions. The animation group required less study time and learned more material. The same results were found in a study by Mayton [30]. Rieber and Boyce [31] compared animation-based instruction with carefully designed verbal presentations, and found that the animation did not result in a greater quantity learnt, but did result in less time required to retrieve information learned. Mathematical learning was studied by Poohkay [32], who compared three forms of instruction (animation, still graphics, and text-only) in a study concerning the use of a compass to create triangles from given line segments. The results showed that students who learned from the animated lesson scored significantly higher than those using the graphics lesson and the text-only lesson.

The use of color is a technique with more varied results. Several studies, such as Wise [33], has suggested that color can be a neutral cue to learning, but can also be distracting if poorly used. However Dwyer [34] showed that color can help when it is an integral part of the material being learnt, and Szabo and Poohkay [35] not noted that educators often perceive color to provide a positive motivational influence. A detailed review is given by Gramoll [36] about the effectiveness and efficiency of animations in the quality of education in his eBook on solid mechanics. As one can see from the aforementioned literature review, the direction of most of the instructor’s tendency in today’s education systems is towards the use of various computer software packages as the supplementary material to effectively teach the course material. Enhancing the classical education with these software packages is expected to increase the quality of both teaching and learning. However, such an approach is still on an individual level and is not advanced enough for a widespread use in the education systems. Therefore, this emerging need should be fulfilled by introducing new innovative approaches with the help of the current computer and software technology.

The approach presented in this article is based on the questioning and visualizing the real life examples of the related theoretical concept by the help of computer-based animation and interaction. The impetus of the present study comes from the issue of problematic gap between the potential of technology and its most effective application in teaching and learning. This initiative will force to propose new model that has the feature of combining application of technology with other innovative strategies to supplement and enhance more the traditional form of instruction.

The goal of this approach is to enhance student learning by developing instructor perspective and skill
in integrating innovative teaching strategies with new development in technology enhanced learning. In the preparation of the courseware, three main goals are considered.

- Have student grasp fundamental principles.
- Have student understand modeling of real problems.
- Teach how to solve the problem.

DETAILED DESCRIPTION OF THE TEACHING AND LEARNING MODULES

Teaching and Learning Methodology

The proposed approach here can be considered as a form of the inductive teaching and learning methodology. In the inductive teaching and learning approach the steps to follow are: (i) giving a specific set of observations or experimental data to interpret, (ii) analyzing a case study, and (iii) solving a complex real world problem. The main advantage of this approach over deductive one is to provide a link between the real world and the theory. There are a variety of methods developed based on the inductive teaching and learning such as inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching [37–42].

The emphasis and style of the proposed courseware differ from most of the existing courses in the following aspects:

- It introduces a software enhanced teaching environment in the classroom that will support sequenced discussions moderated by instructors and rich textual as well as graphical communication between students and instructors.
- It introduces students to the methodology through simple, yet practical, examples to stimulate their interest in engineering before exposing them to rigorous math.
- It gives students a better “feel” for the topic by graphical visualization of problems and interactive virtual experiments.
- It allows different target groups to select individual paths through the course, paths tailor-made to their needs, and respective of their background knowledge.
- It encourages self-study combined with investigative and collaborative modes of learning.
- It integrates computers into the course curriculum.
- It employs the computers not only for equation solving, but also for formulation of equations thus avoiding an unnecessary distraction for students from the study objectives.
- It gives students the opportunity to benefit from “organizational learning,” that is, from utilizing knowledge recorded during previous problem solving both in academia and industry.

This approach has three main ingredients called “modules,” “templates” and “computer enhanced rich material.” There are many challenges to overcome during the preparation of these ingredients. These challenges arise mostly from satisfying the following criteria [43–46]:

- Analyzing the needs and characteristics of the different people involved in developing and using a multimedia system for engineering education.
- Analyzing the range of learning tasks and levels of learning that could be facilitated by a multimedia system for engineering education.
- Designing a multimedia system based on this analysis and on shared content that can be used for identifiable learning tasks and that can be explored to meet additional potential needs.
- Designing a courseware that should have a clear statement of and support for appropriate learning objectives and goals.
- Enabling the learner who should be actively involved in the learning process via interaction with the courseware and other learners.
- Developing a program with superior graphics quality that is likely to have the direct influence of raising student interest and motivating students to utilize the educational software.
- Developing modules that become attractive and user-friendly if the majority of steps required to run the program are handled by the graphical user interface.
- Developing modules where the computer program used is simple to understand and to use and the interpretation of the results are facilitated. This way the learning effort is concentrated on the subject matter of the course, not on the technical details of the program being used.

Structure of the Course Modules

Modules are formed based on two templates that help one to create the more systematic and modular form for the course material. First template of the modules is created such that it consists of a module number,
a module title, a description of module aims, a
description of module prerequisites, a description of
module outcomes, and the module units (Fig. 1). One
can upgrade this template easily by adding more items
such as module’s problems, sources codes, games, and
references. With this template it is aimed to provide
a hands-on guide and brief but concise information
that the module covers and also to inform of the
consequences of the newly learned module. Most of
the students usually are not aware of the aim of the
subject and do not realize what they will gain at the
end. Such lack of information greatly affects student’s
ability not only to approach the subject analytically
but also to establish a link between the subject and its
related fields.

Second template of the modules is designed to be
based on four steps to present the contents of each
module’s units in a better and more systematic way
(Fig. 2). These steps are as follows:

- Visualizing.
- Modeling.
- Theoretical expression.
- Interactive examples.

These four main steps are then prepared based on
the concept questioning along with interactive learn-
ing approaches that integrate a real life application
of the relevant theoretical concept and computer
modeling into classical lecture topics of engineering
education. The schematic illustration of the proposed
teaching and learning methodology is shown in
Figure 3.

In the framework of this structure, the course
topics are divided into the following two areas: (i)
Software Enhanced Course Modules, and (ii) Virtual
Lab Experiment Modules. Software Enhanced Course
Modules consists of 14 modules that cover some
important topic of the engineering mechanics and
dynamics of the mechanical systems. Virtual Lab
Experiment Modules contain eight modules that cover
the fundamental tests of strength of material (Fig. 4).
The content of these modules are available in two
formats; DVD and online. The materials in DVDs are
prepared as flash presentations in order to make them
readily available in class use without requiring any
additional source. On the other hand online materials
are put within the learning platform MOODLE, which
is a course management system where the user can

Figure 1 Screen captured picture of a template that shows a guide hand information of a module.
[Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]
Figure 2 Structure of the template that shows details contents of a module. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Figure 3 Schematic illustration of the proposed teaching and learning methodology.
work independently, or work as a team with people from the same class, or even from a different school far away. The online material can be reached from the CemLib project’s website at different locations (cemlib/mku.edu.tr, cemlib.zmml.uni-bremen.de, virtual.cvut.cz/cemlib).

Software Used to Develop the Materials

These supportive modules are prepared by using Macromedia Flash [47] and 3D Max [48]. Macromedia Flash is a software development environment designed to create and deliver rich web-content and powerful applications. It can be used to design motion graphics or to build data-driven applications. It is also portable across multiple platforms and operating systems. Macromedia Flash is also an authoring tool that allows creating anything from a simple animation to a complex, interactive web application that can be made media-rich by adding pictures, sound, and video [49–52]. Macromedia Flash includes many features that make it powerful but easy to use, such as drag-and-drop user interface components, built-in special effects, called ActionScript that can be added to objects in a document [53–56].

3D-Studio Max is a tool from Kinetix for making 3D Models and Designs and also to create simple as well as complex 3D animations [57]. It has useful features such as mechanical 3D Modeling and rendering, architectural drawings and layouts of all kinds, interior design and facility planning, line drawings for the fine arts, etc.

Using 3D-Studio Max, one can easily achieve the fluency required in the animations consisting of multiple steps. Impressive presentations can be created by using simple 2D drawings and projecting them into dynamic views, resulting in vibrant 3D drawings with animations and light effects.

DETAILS OF THE MODULE CONTENTS

Visualizing

Many instructors are often disappointed with the extent to which students are able to use theory when faced with the analysis and design of real systems and structures. Therefore this section is constructed with the following goals:

- Build a bridge between real life and theory.
- Encourage students to avoid memorization of mathematical expressions and definitions of the theory without understanding their meaning.
- Enable them to think globally and to act locally.
Similar to Kolb’s [58] experimental learning model that involves four questioning steps in this part the conceptual questions come into play to provide a better visualization of the topic being taught and types of thinking this specific unit of the module is intended to teach. The focal question, “why?” is used to get the attention and focus of the student towards the subject by relating to student’s interest and experience. With “what?” questions, opportunity is given to students to show their reflection on the presented facts, experimental observations, practical applications, and principles. Basically these little questions are thrown to students to draw their attention to visualizing the real systems. This also helps students in understanding the limitations of the subject well before going into rigorous theoretical part.

**Examples.** Today’s computer technology and modern software enable us to bring many real world systems into classroom or to embed them into our lectures on the online environment. Such facilities not only sophisticate teaching materials of the instructors but also help students see the real systems of the subject of interest. This sophistication of the course materials with the enhancement of the computer software can be easily seen in the figures presented, which were obtained by capturing the screen. In Figure 5 the illustration of the working principle of catapult is an example to show how the concept of vector addition with the parallelogram law can be related to a real world problem. This dynamic presentation immediately invoked the student’s minds to think of similar systems that work under the same concept. Most of the students gave, for instance, “slingshot” as an alternative example. They were also stunned by the realistic representation of such a real world problem in computer graphics.

![Figure 5](image)

**Figure 5** 3D Max modeling of a historical catapult for visualizing the vector addition concept of parallelogram law. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

It is also possible to bring the video recording of the real life events into the classroom. For example, Figure 6a shows a video of deformation behavior of a bridge during an earthquake. This gives a very good feeling and visualization to students of how a solid structure undergoes deformation with dynamic loads. This video can be extended to include all steps from the real structure to modeling of its 2D or 3D frame structure, its design with a software package specialized in bridge design, and finally analysis results of the simulation of the behavior of the bridge in terms of displacements, deformations, and stress distributions. Such videos that depict the complete process from design to realization of a structure will make more meaningful the relevant subjects taught in courses such as Strength of Materials, Structural Analysis, or Structural Dynamics. In Figure 6b a video recording of tensile testing is shown. Another advantage of such videos is that the students can view the experiments without going the laboratory. Yet another advantage of these videos is that they motivate the students to understand the underlying mechanics of design and analysis of structures because the students can relate the course topics to real behavior of structures and as a result, they feel compelled to understand the relevant theories of mechanics.

**Modeling**

Once visualization of the theory is provided next step is to write down real life scenarios on a paper or a blackboard with a more simplified and representative form by using drawings, shapes, and diagrams. During this simplification it is important to make the students understand the principles, assumptions and limitations of the theory so that they can learn to what extent the real world can be modeled using this particular theory. This is a very important section that provides a direct link between a real world and its theory. In the classical educational system, the model of a problem is usually directly given to students. Thus, most of the time students have difficulties making connection to the real world systems from these simplified drawings. This is evident from the fact that they cannot adequately establish a simplified model for a given real life problem.

Computer technology with its highly developed powerful software plays an important role in today’s modern educational system by providing a link between reality and theory interactively. This provides an opportunity not only to create complex real scenarios in class environment but also to show each detail for various steps of modeling so that the students can understand the process of development.
and deployment of theoretical equations for the solution of the problem of analysis or design.

Examples. An illustrative example is given here from the stress module to show the steps that are followed to establish the model from the real system problem. In this simple example, a modeling step of the concept of nominal stress is visualized by a snow man walking on snow (Fig. 7). Figure 7b is obtained at the end of animation to show the forces acting on the body. From Figure 7b a more simplified graphical representation of the problem can be established (Fig. 7c). In classical lecturing this is usually a starting point to talk about the concept of the theory by linking to its real system only verbally and to derive related mathematical equations.

Theoretical Expressions
At this point, students are usually aware of the real life problem, its visualization, modeling, and limitations if the previous steps of visualizing and modeling are implemented effectively. In this step, like in deductive teaching, initially fundamental principles are given and then mathematical expressions are developed using these principles. Student have now more clear minds from the material presented in the previous steps about where and how they are going to use these mathematical expressions. This completes the link between top scale, the scale of real systems and bottom scale, the scale of mathematical expressions.

Example. In Figure 8 this fact is illustrated by showing the screen captured static picture of a flash animation where the dynamic and interactive explanation of the definitions, derivation of the mathematical relations, and systematic solution steps are presented. Without hesitation of the space limitation or carrying a large amount of different source materials some of the helpful information can easily be loaded into this type of lecture notes. As a simple example in this lecture notes we presented a brief bibliography on Thomas Young.

Interactive and Animated Examples
Animated and interactive examples are prepared to strengthen students’ ability on the conceptual understanding, visualizing, modeling, problem solving, and interpretation of obtained result of the subject being taught. In these examples more attention are given for integration of steps present in the previous sections such as visualizing, modeling, and theoretical expression in a stepwise fashion. In these steps students would learn; identify and collect appropriate
evidence to visualize the real system, able to model the real system in simplified form, formulate theoretical part, analyze and interpret result, present results systematically, formulate conclusion, and evaluate the significance of the conclusion.

Examples. A simple example is presented in Figure 9 to illustrate above-mentioned procedure in integration steps in the solution of a simple engineering mechanics problem. Figure 9a shows a dynamic interactive movie crated for the visualization of a real world system. When this movie is further played it shows the next step, which is modeling of the real world system in a more simplified graphical representation (Fig. 9b). This dynamic transition from one step to another helps students establish easily the link between the steps. At the final stage of the movie the equations are formulated, the solution steps are explained, and the significance of the results are discussed (Fig. 9c).

Some of the examples are prepared in an interactive form so that students can do some parametric study on the related problems to investigate the various effect of each parameter on the solution of the problem (Fig. 10). Such interaction builds up student’s ability to evaluate better the different cases of the same problem with different values of its parameters and also to interpret the results.

DESIGN OF PILOT COURSE FOR THE IMPLEMENTATION OF THE COURSE MODULE

Although the main focus of this article is to present a novel teaching learning methodology enhanced with computer technology, a preliminary short-term evaluation is sought here in order to establish the effectiveness of the method and to validate the findings. These modules are used in class teaching of the course Engineering Mechanics taught to civil engineering students for one semester at the Mustafa Kemal University where author has been teaching this course for several years. In addition to these regular class lectures, 2 h lectures were also organized at different universities in Turkey. The participating universities were Cukurova University (CU), Adana and Gaziantep University (GU), Gaziantep. The lectures were given with prepared course modules to both civil and mechanical engineering students. Students were first lectured in the class environment with the use of these materials. They were also allowed to access the materials on the web in order to be able to repeat the material whenever they wanted. Several quizzes were given to students after finishing the subject in the class. Their successes from these exams were evaluated. Total number of students that were involved in this field type testing is 383. A questionnaire was prepared and distributed to all the students who were lectured with these materials.

After the lecture, the participants completed the assessment questionnaire. Quantitative survey responses were entered in a spreadsheet for analysis. Descriptive statistics were obtained in charts and tables. The students’ overall evaluations were found highly positive as it can be inferred from the following findings:

- On average 71% of students found the material helpful for their comprehension of the course topics (Fig. 11).
- When they are asked to give their opinions about “whether supporting visual learning by animations makes the concept more tangible,” 85% of students answered positively (Fig. 12).
Figure 9  (a) Dynamic interactive visualization of a real system. (b) Modeling stage of the real system. (c) Solution steps of the example problem. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]
When asked “if they would use these materials to understand the concepts,” 72% of students said that they would continue using the materials for their own learning (Fig. 13).

About the course material some of the students wrote comments such as:

- “Generally, the computer animations had beneficial effects on me for understanding the course subjects.”
- “Animations helped me visualize some of the difficult concepts in course.”
- “I better understood the cause—effect relations using these materials.”
- “The animations have contributed to the development of my ability to critically analyze a problem and to my analytical thinking skills.”
- “Supporting visual learning with animations makes the concepts more concrete.”
- “Animated concepts stimulate my analytical abilities by helping me find similarities and differences in the fundamentals of the topic.”

When these figures are closely examined in view of the positive reactions from students, it becomes clear that the response of different disciplines and universities share some affinity. This indicates that the lectures are effectively delivered, and that to some extent, the objective of the proposed interactive learning and teaching methodology is achieved. An in-depth examination of the validity of the proposed
approach will obviously require a long-term evaluation process. The data collected from this evaluation will subsequently be analyzed to determine the efficacy of the material presented within the proposed approach. This will be an issue of a forthcoming article.

CONCLUSION

The computer enhanced teaching and learning modules developed using the inductive teaching and learning methodology are presented here. The effectiveness of these modules was evaluated in a short-term study in three different universities where the same course was regularly taught. It was found that these teaching and learning modules provide the following features and advantages:

- They provide modular and template form for systematic representation of the materials that provide opportunity for its integration modules to the related subject and updating modules and templates easily.
- They enhance the understanding of the theory and its complex math on the textbooks.
- They allow demonstration of modeling and simulation of the large-scale models, which is not possible in the classroom at such large extent.
- They provide convenient usage of the developed material in classroom and at home as many times as needed with little effort.
- They channel the efforts of the students to analytical thinking instead of memorizing examples and formulas.
- They improve the efficiency of the classroom lecture and thus reduce the time dedicated by the student out of the classroom.

Although computer enhanced teaching and learning approach requires more time and high skill in its initial development stage of such highly interactive teaching materials, it is obvious that their use as supportive material to traditional teaching will increase level of the students from low order thinking to higher order thinking; improve the students confidence and ability in analytical thinking and help them avoid memorizing and provide the instructor more possibilities to better deliver his lecture. This approach is also strongly rooted in the idea that students learn new concepts by building upon what they already know. New ideas presented here indicate that students can build upon their existing ideas and learn interacting with instructors. Student response to the short-term evaluation period indicated their enthusiasms for using the courseware and their positive assessment of its usefulness for learning.

It should be clearly emphasized here that instructor, blackboard and chalk, triangle of classical teaching system never thought to be replaceable. It is considered that the technology-based developed materials are not a substitute of classical teaching materials but they can significantly improve the efficiency of both lecture and learning.

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