Asynchronous Computer Based Training as a Means of Integrating the Use of Engineering Software into the Curriculum

Stephen W. Crown
Robert A. Freeman
Arturo Fuentes
Department of Mechanical Engineering
University of Texas – Pan American

Abstract: The continuous growth in the use of engineering software in the practice of engineering has impacted engineering education. Graduates are increasingly expected to be familiar with several engineering software packages. Although the use of engineering software has allowed for the removal of some course content, there is still not adequate time to teach the use of software in the classroom. The use of asynchronous computer based training provides an effective means of instruction of engineering software that is self paced and does not take away from class time used to cover theory and fundamentals. Students react positively to the computer based instruction since it can be accessed on their schedule, at their own pace, and repeated as necessary. Obstacles to the development of materials have been overcome through the use of inexpensive screen capture software that is easy to use and can be produced in minutes. Such software has been used in Mechanical Engineering to teach Pro-Engineer in a Freshman Engineering Graphics course, MathCAD and Working Model in a Kinematics and Dynamics course, LabView in a Measurements and Instrumentation course, and is being developed for teaching Visual Nastran in a Finite Elements course. The initial impact of introducing asynchronous computer based training in each course is discussed in addition to the methods used to develop materials. A web-based faculty development resource is described that is available to assist in the development of like materials and as a repository for developed materials.

INTRODUCTION

Engineering education faces a new challenge with the growing power and propensity of computers. Engineering software is readily available that allow for design, simulation, analysis, and control that push the capabilities of a trained engineer to new heights. The power of these new tools has become such that it is hard to imagine the practice of engineering without them. While these new tools have lessened the importance of some engineering content the majority of the engineering curriculum has been unaffected. Although students need to be familiar with the new software it cannot come at the expense of a solid understanding of the fundamentals of key topics taught in the classroom. If significant time cannot be diverted for the teaching of software in the classroom other methods must be used.

Asynchronous computer based training gives a powerful alternative to classroom instruction for the teaching of engineering software. The teaching of core engineering principles requires interpretation and a developed understanding that generally requires discussion with the instructor. The learning of engineering software however is more easily adapted to computer-based training. One of the key advantages of computer-based training is that the training and student interaction with the software occurs on the same platform. The use of asynchronous

delivery allows students to enter the training at the appropriate level. Students can select additional training in areas of weakness and skip ahead if they are familiar with a topic. Additionally, students can receive training on their own schedule and at their own pace. The materials can easily be delivered through the Internet or on CDs making training available in computer labs or on home computers. Finally, the instruction can be repeated and reviewed if students need repetition to grasp and retain instructions.

One of the roadblocks to the extensive development of computer-based training has been the required investment of time. The development of real-time screen capture technology has reduced the investment of time to that of classroom instruction with the advantage that it can be delivered asynchronously outside of the classroom. Four courses were identified in the mechanical engineering curriculum where significant teaching of engineering software was required. Pro-Engineer is taught in a Freshman Engineering Graphics course, MathCAD and Working Model are used in a Kinematics and Dynamics of Mechanisms course, LabView is taught in a Measurements and Instrumentation course, and material is being developed for teaching Visual Nastran in a Finite Elements course. Under funding from a NSF CCLI grant, instructional materials were developed which incorporates screen capture movies for use in asynchronous computer-based training.

SCREEN CAPTURE

The development of instructional materials for the teaching of engineering software has been made possible through the use of real-time screen capture software. Although several screen capture programs exist, Camtasia by TechSmith was selected for its compatibility with other software, minimal impact on the processor, ease of use, and compression of output files. The program operates like a simple tape recorder. A record button starts the screen capture and a function key stops the movie and saves to a file. The program can be configured to visually display mouse clicks, highlight the cursor position, and record audio and screen activity in real time.

The screen is relatively static for most instruction, which significantly reduces the size of the screen capture movies. Most movies were recorded at a screen resolution of 600x800 with eight-bit color. The audio format was set to eight-bit mono sampled at 11kHz using PCM compression. With these settings and typical screen activity for teaching software applications the movies require about 1.0MB per minute. It is therefore possible to record several hours of instruction on a CD, which can easily be distributed to students. The files can be saved as AVI files that can be played with the Windows media player or any application that plays AVI files. The Real One Player plays movies back full scale by default, which is a distinct advantage when trying to read small text such as menu items in pull down menus. The choice of 600x800 resolution for screen captures gives sufficient screen size for most applications and gives room for the Media player controls when viewed. Although the movies can be played back using full-screen mode the students are encouraged to jump back and forth between the application and the movie. This is most easily accomplished when both the application and the movie are visible on the screen.

ENGINEERING GRAPHICS

The screen capture movies were first developed for the engineering graphics course out of a tremendous need for individual assistance in the lab. The diversity of student backgrounds and abilities made the group teaching of CAD software very ineffective even with the use of lab assistants. After an hour of classroom instruction some students had retained all of the instruction and were ready to progress while others were stuck on the first set of instructions. In an effort to keep everyone in the class productive a number of screen capture movies as shown in Figure 1 were made that walked the students through the homework assignments. The movies were simply recordings of the instructor doing each homework assignment. The first set of instructional movies comprised of approximately 10 hours of instruction used over a fifteen-week period. The materials were delivered on a web site with access to lecture notes, games, and quizzes as described in an article by Crown (1999).

The use of the instructional movies in the lab significantly changed the pace of the course. Students that caught onto material quickly would watch the movie in its entirety and then do the homework on their own using the knowledge they had gained through watching the movie. These students were not impacted by the development of the movies and had been successful with classroom instruction. The majority of students, however, would watch a portion of the movie
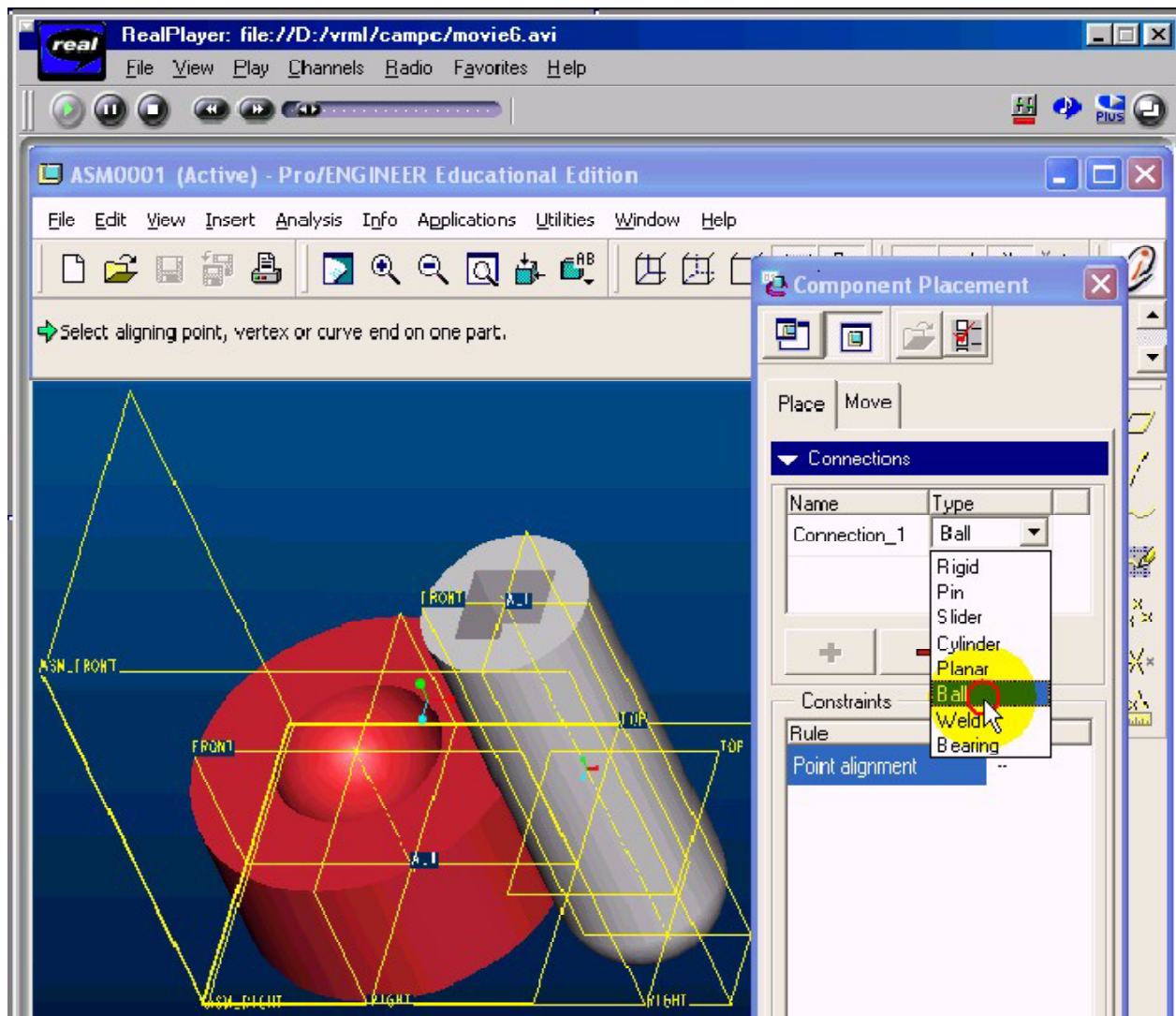

Figure 1. A tutorial movie used to walk students through the homework step by step.

and stop to complete a small number of steps. If they had difficulties they would rewind the movie and review the instruction. Although students progressed through the materials at different rates, almost all students were able to successfully complete the assignments without needing any extra assistance.

As students were able to progress through the material at a greater pace it was possible to add more content to the course. With the addition of the instructional movies, several weeks of solid modeling was added to the curriculum and more time has been devoted to sketching. Almost no classroom instruction is devoted to teaching the CAD program as it is completely taught through the use of the movies. Recently, the CAD platform was changed from AutoCAD to Pro-Engineer. Some concern was expressed that students might not be able to learn Pro-Engineer in an introductory level course. The use of instructional movies has been used successfully for two semesters with Pro-Engineer. Additionally, students who took the course using AutoCAD are now able to access the Pro-Engineer training materials and update their skills without having to retake the course.

The materials developed for Pro-Engineer consist of about 6 hours of instructional movies that walk the student through the design of a catapult. The instructional movies are delivered through a virtual world interface. The students explore the virtual world and are instructed by individuals that they encounter. The virtual world lets the students see what they are building before they begin. The virtual world instructors are arranged in camps that the students visit in order. In Camp A, the students are instructed to copy sketches of a catapult base and are then introduced to the CAD program and create an assembly of the base in Pro-Engineer. Most students are able to complete the assembly by the first week of class. The ability to create the assembly in their first exposure to the program motivates the students. By the second week of class many students have forgotten how they made the assembly and need to review the previous materials. On review, however, they recreate the assembly in a fraction of the time.

As students progress through the camps, they learn how to use more complex tools and begin to work on their own. In Camp B, the students are shown how to make the left-hand parts but must make the mirror image parts on their own. In Camp C, the students must reverse engineer a captured catapult. They are given general instructions in the tutorial movie, shown in Figure 1, about the creation of ball joints, sliders, plane and cylinder connections, however they must apply this knowledge to the specific slider connection used on the catapult on their own. Finally, after several weeks the students are ready to work on their own using program tools that they are comfortable with and that are easy to review if they need to return for instruction. The use of the virtual world and the framing of instruction around a design project helps the students put the learning in context and makes it more interesting. It is interesting to note that instructional materials not directly related to the design project or homework assignments were rarely used.

Although the materials did not need to be delivered in a classroom setting, a choice was made to require the students to attend a scheduled lab time to use the instructional materials. Without the structure of a regular class meeting time many freshman would lack the discipline to set aside three hours for instruction each week. Students that did not finish the work or that missed the class, however, are able to return to the lab on their own schedule to complete the work. The

interaction between the students and the instructor has changed from an overwhelming request for help with technical problems to conceptual questions about course content or technical questions about advanced features of the software. Almost all students now turn in homework assignments, their work is usually completed without mistake, and they rarely come by during office hours.

KINEMATICS AND DYNAMICS OF MECHANISMS

Kinematics and Dynamics of Mechanisms is a 3 credit hour course aimed at introducing Junior-level students to issues involved in the kinematic synthesis, dynamic analysis, and "optimal" design of co-planar mechanisms, with an emphasis on four bar linkages. The math and engineering software incorporated and "taught" in this class includes MathSoft's MathCad and MSC's Working Model 2D. The course outline is reproduced in Table 1 and shows that we begin with the description of the basic elements that comprise all mechanisms, followed by a survey of simple

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KINEMATICS AND DYNAMICS OF MACHINES

Introduction
Fundamental Concepts; Joint & Link Types, DOF
Linkage Classification, DOF & K. Equiv. Diagrams
1-DOF Mechanism Model (KIC-based)
Survey of Simple Mech. Devices;
- Constant Gain;
- Constant but Adjustable Gain.
- Cams, Differentials & Misc.
- Epicyclics

Design Theory and Methodology and Gear Train Examples
Dimensional Synthesis; Concepts
Tools; Curvature Transform
- Coplanar Motion Synthesis
- Coplanar Motion Synthesis
- Cognates - Angular & Path

Solvable Tasks;
- 2 Link Chain, 2 Cranks, & Slider and Crank
- 2 Cranks via Inversion
- Path Coordination with a Crank
- Other Synthesis Techniques

4R-4Bar Analysis
- Position Analysis
- Velocity., Acceleration., and Force Analysis
- Shaking Force and Moment Balancing

Kinematic Influence Coefficient (KIC)-Based Dynamic Modeling
- Mass and Externally Applied Loads
- Springs and Dashpots (Viscous Friction)
- The Controlling Equation & Transfer of Input

Dyad Based Mechanism Analysis
- Structures
- Position Analysis
- Velocity/G-function & Acceleration/H-function Anal.
- Force Analysis

Lead in to Machine Elements & Senior Design

Table 1. Course outline for Kinematics and Dynamics of Machines course

mechanical devices including gears, cams, and differentials, and continue on to general 1DOF co-planar mechanism modeling and analysis using a "dyad" based approach. The point being that there is barely enough classroom time to cover the desired technical content, much less time to teach the use of appropriate math and engineering software.

The approach taken in this course to deal with the lack of classroom time incorporates the use of "screen capture with audio" AVI tutorials, along with a variety of interactive materials, to help deliver not only course content but also software use instruction. Specifically, Word documents with links to "screen capture with audio" tutorials, and interactive Mathcad and Working Model 2D (WM2D) example "scripts" are used as the delivery modes. The interactive materials include; supplemental lecture notes summaries, homework assignments and solutions, sample exams and exam solutions, and sample projects. Materials are also developed to help the student use the software packages' own assistive materials. A detailed presentation of all the materials developed for the course is given by Freeman (2003).

Sample Project
The project requires student teams (limited to 3 students) to propose a task that can be solved using a four revolute 4-Bar (4R-4Bar) linkage. They are encouraged to select a task that can be formulated in terms of either Co-Planar Motion Synthesis, Angular Coordination of Two Cranks, or Path Coordination with a Crank as these procedures are directly treated in class and result in 4R-4Bar solution mechanisms. They are then required to obtain two different kinematic solutions to their problem. This is to be done using Mathcad to obtain analytic solutions, and then Working Model 2D to "virtually" verify the solutions. They must also build a physical model of one of the solution 4Bars. After obtaining two valid kinematic solutions they then proceed to perform a dynamic analysis on one of the solutions in one position (state) by hand and with Mathcad. They then use WM2D to dynamically simulate the mechanism. They are required to obtain the same values for the link accelerations, joint reaction forces, and the required motor torque that they obtained by hand and with Mathcad. This is intended to verify that they are both using WM2D correctly, and that their "by hand" / Mathcad analysis is correct. Finally, they compare their two kinematic solutions dynamically using WM2D under realistic operating conditions for their task and select one as their "optimal" design based on some dynamic metric, such as minimum maximum required torque magnitude. Examples of the tutorials movies are given below.

Synthesis Tutorials: First, Working Model 2D is used to illustrate a graphical approach to the solution of the "Three Finitely Separated Position" (3FSP) Co-Planar Motion Synthesis (CMS) problem with moving pivot specification. In the process, a number of Camtasia tutorials show the student how to use WM2D to create and dimension a 4-Bar linkage, and create measures and controls. As seen in Figure 2, once the AVI is created it can be played in any player software.

Second, a Mathcad script is used to analytically solve the same 3FSP problem. As seen in Figure 3, the student is also taught, via a Camtasia tutorial with textual descriptions within the script and with the aid of the Mathcad Resource Center, how to reproduce the script, and how to use Mathcad to solve systems of linear and non-linear equations, and to create 3D scatter plots with line generation.
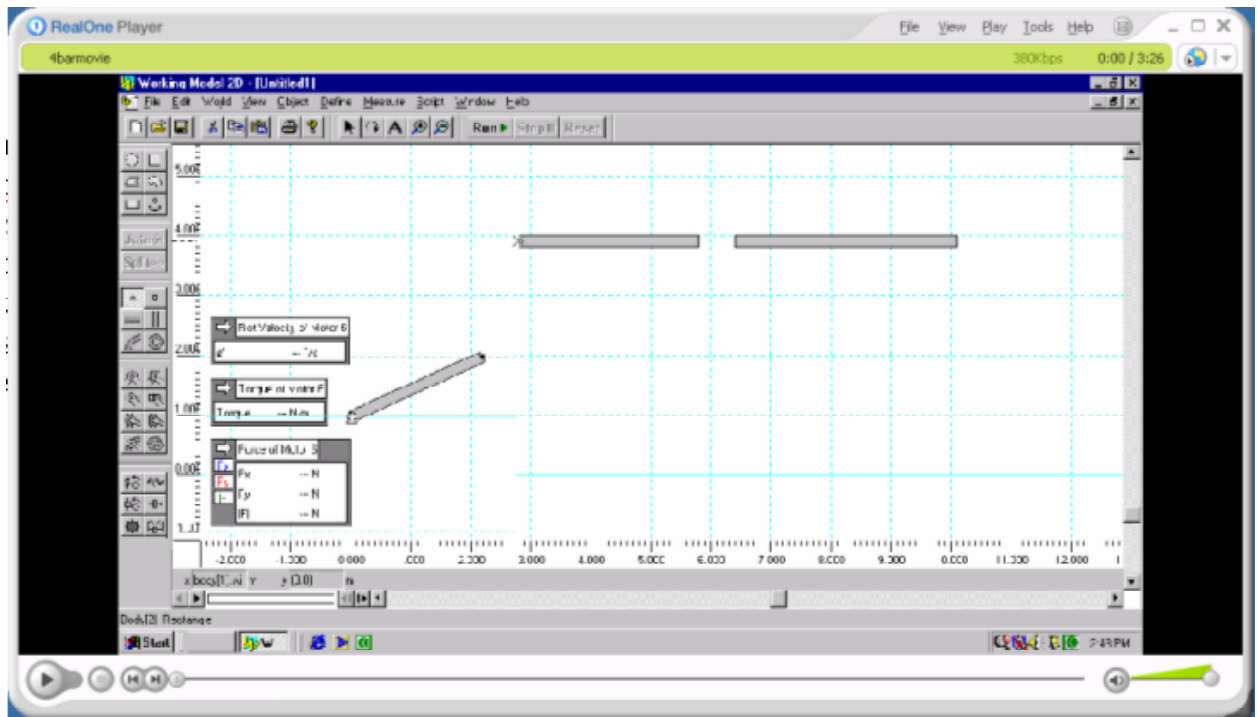
Figure 2. A tutorial movie showing how to use WM2D to create and dimension a 4-Bar linkage
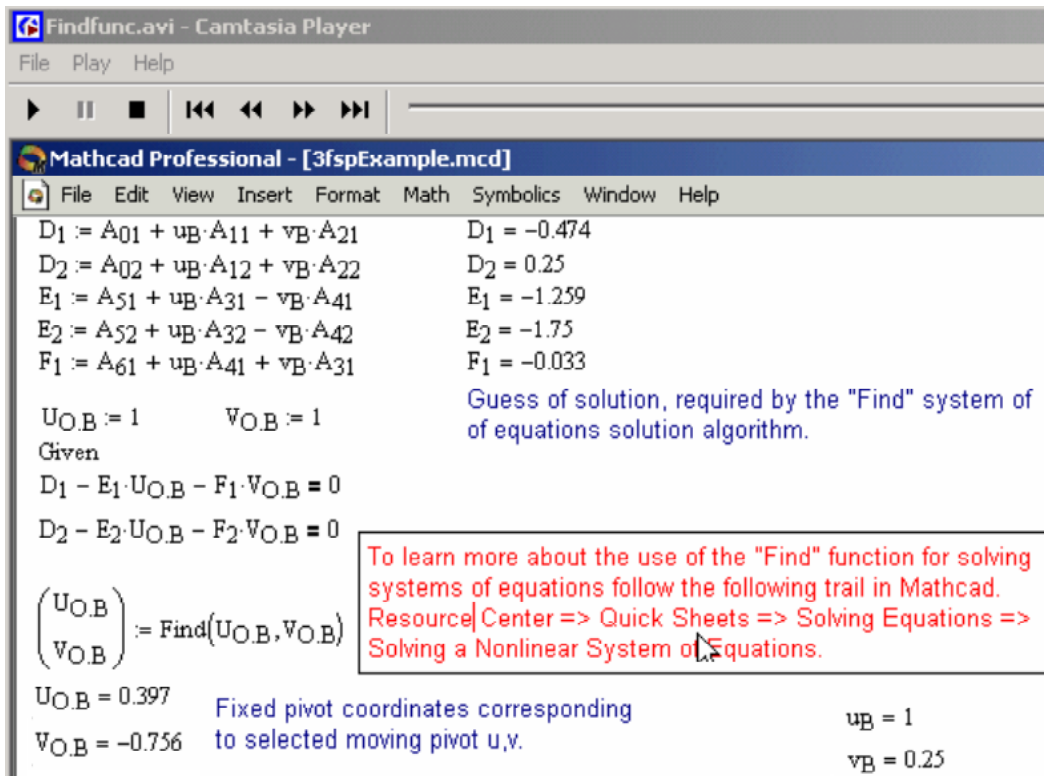

Figure 3. Tutorial movie showing how to solve a system of non-linear equations using MathCAD.

Analysis Tutorials: The students are required to create a dynamic simulation of one of their kinematic solutions in WM2D and compare the resulting accelerations, forces, and required motor torque with a corresponding solution obtained using Mathcad. In the process they are shown how to assign masses, inertias, centers of mass, initial velocities as seen in Figure 4, and motor type (acceleration) using Camtasia tutorials. They are also shown how to relate the link frames assigned by WM2D to those used in the development of their Mathcad solution in order to have the centers-of-mass in the same physical locations.
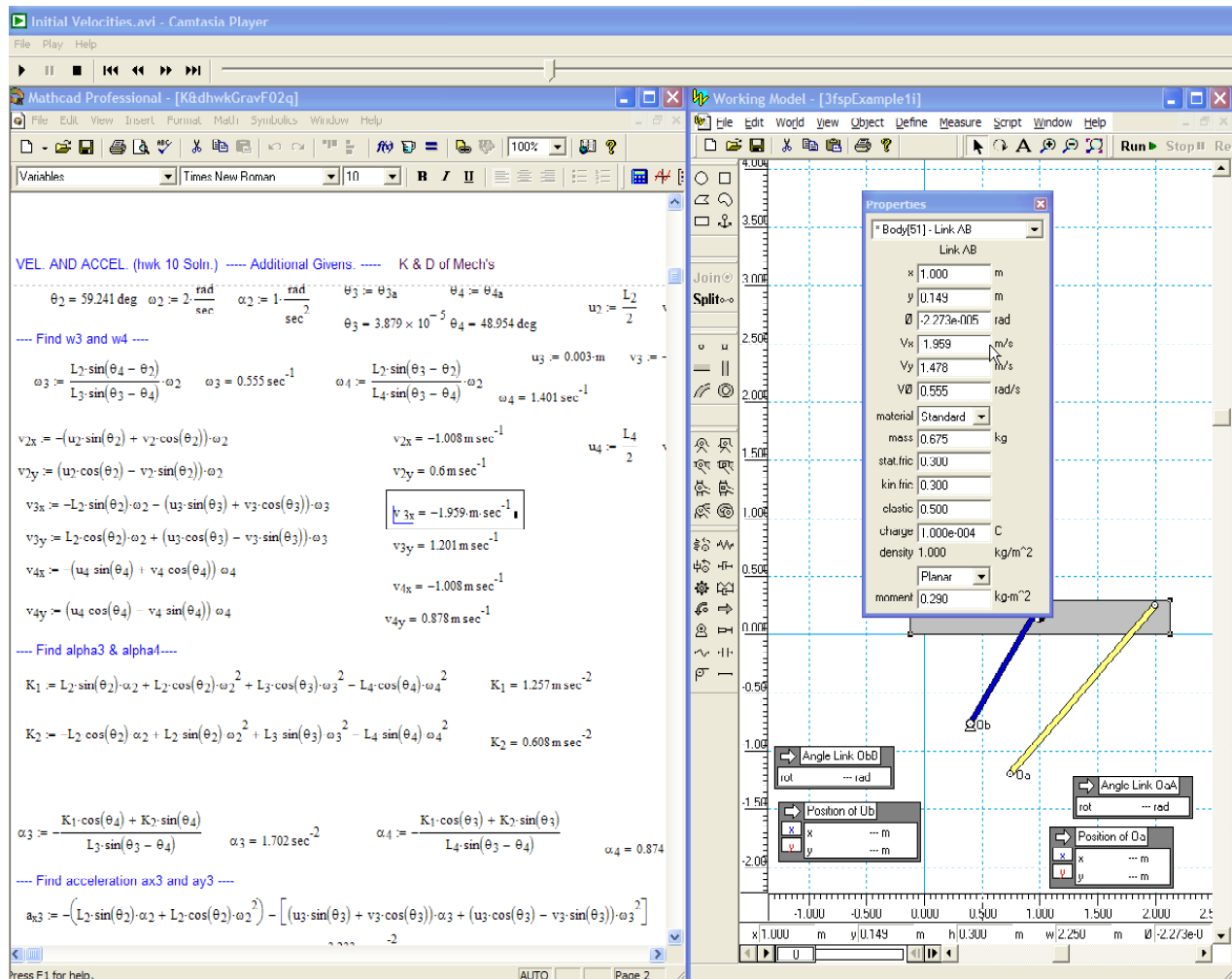

Figure 4. Tutorial movie showing initial velocity assignment.

Observations

While these "screen capture with audio" avi tutorials are particularly effective for instruction of GUI type software such as Working Model, it is still beneficial to the student to have a verbal dialog along with a "textual" presentation of how to access and use certain features of software such as Mathcad.

While there is no hard evidence yet, the results of partial implementation of this approach in Fall 2002 are very promising. Full implementation of this approach is planned for Fall 2003, along

with formal assessment and evaluation. The use of Mathcad and Working Model 2D (without any additional instruction) in follow-on courses in Machine Elements and Senior Design will also aid in the assessment and evaluation of these materials.

MEASUREMENTS AND INSTRUMENTATION

Prior to the implementation of computer-based training in the Measurements and Instrumentation course, two weeks of instruction were devoted to computer data acquisition and programming with LabView. Since it was not possible to devote more class time to this subject five hours of lab instruction were set aside for LabView instruction for a total of approximately eight hours of instruction. Additionally, students purchased a book that walked them through the commands and several example problems. The book also included the software and example programs so that the students could learn the program at home or in the lab on their own schedule. After two semesters of using lecture instruction and the book, it was clear that students were not learning how to write programs. Almost none of the students could write a their own programs and during the second semester all thirty students failed the second take-home exam on LabView programming. An optional half day seminar was offered to help students learn LabView before the final however, students still performed poorly on the exam.

To address this problem the following semester, a series of thirty screen-capture movies were created that walked the students through several example programs using LabView. The movies taught basic programming concepts such as the formulation of algorithms and defining necessary program variables and was posted on a web site and made available on CDs. The students were given two weeks to review the computer-based training in lieu of two weeks of lab instruction. The instructional movies took about ten hours to complete for an average student. Several students learned to program in LabView using the tutorial movies but the majority of students did not use the instructional material as was discovered on a student survey given at the end of the course.

The following semester a combined approach was used where the students were introduced to the program in the lab at a required lab session and were walked through a number of simple programs by the instructor. Students used the second half of the lab period to view the instructional movies in groups of twos. Students were then assigned several hours of independent instruction on their own using the tutorial movies during the week. The second week followed the same format. The increase ability in student performance was tremendous. Almost all students were able to write their own LabView program for numerical integration and a binary to decimal number converter. The students wrote a similar program in the instructional period. Many students were also able to create a new program shown in Figure 5 that calculated the time constant for a thermocouple using a data acquisition card. Although the students received six hours of classroom instruction in addition to the computer based training most were able to learn how to use the software by the end of the semester.

The experience demonstrated the student motivation and discipline is a significant consideration when using computer-based training. When offered self-directed training on a flexible schedule most students did not take advantage of the training even when they knew that they would likely fail the upcoming exam. Intensive classroom instruction required the scheduling of additional class periods and also did not yield acceptable results. The classroom instruction did not give
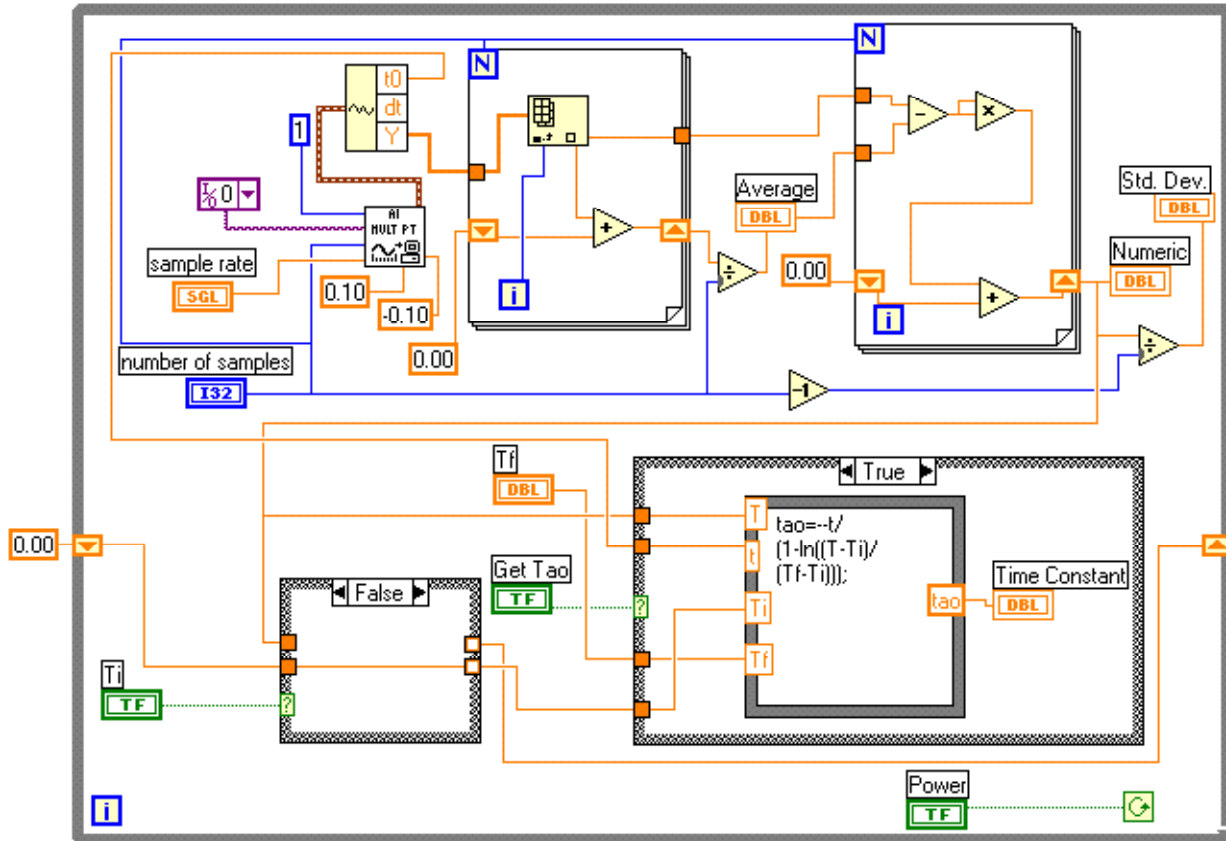
Figure 5. Example program written during in-class LabView exam.

students time to process the information at their own pace or the ability to review the instructional material. Students performed best when offered computer-based training that could be viewed at their own pace but with supervision and with scheduled times for using the materials. The students performed best with the computer-based training but lacked the discipline to set aside the time to use it.

Finite Elements

The finite elements (FE) course offered by our department is another typical example of an undergraduate class where our content overfills the semester and where the importance of a course that is design-oriented, with a substantial component involving the use of a commercial software package, has been underlined by our faculty. As opposed to other undergraduate courses, the use of engineering software in this finite element class does not allow for the removal of any course content. In fact, engineering software supplements theory and course content. For instance, the topics selected for this semester include:

- Introduction to Finite Element Analysis
- Review of Matrix Algebra and Methods for Solution of Simultaneous Linear Equations
- Stiffness Matrix for a Spring Element (1-D)
- Development of Truss Equations (2-D)
- Development of Beam Equations

- Plane Stress and Plane Strain Stiffness Equations
- Practical Considerations in Modeling; Interpreting Results; and Examples of Plane Stress/Strain Analysis
- Axisymmetric Elements
- Isoparametric Formulation
- Three-Dimensional Stress Analysis
- Heat Transfer
  Furthermore, other topics to be covered if time allows include:
- Development of Linear-Strain Equations
- Plate Bending Element
- Structural Dynamics

The ongoing Visual Nastran Computer Based Training project, described in the following paragraphs, is part of an effort that consists in the development of an integrated web site with links to different Finite Element Analysis software tutorials, FE study cases, lecture presentations, web-based FE games, and a series of interactive web-based FE quizzes that reinforce students' engineering judgment and increase students' software exposure.

The use of asynchronous computer-based training, which does not take away from class time, is currently providing an effective means of instruction of Visual Nastran at the same time that the students are learning the theory and fundamentals. The producer of Visual Nastran software provided a set of "Getting Started" tutorials that cover the basics and which have served as an important starting point. These tutorials complement the information available in electronic and printed manuals. We have found that these tutorials by themselves have already helped some students remove initial intimidation to learn the software and gain confidence to further explore available capabilities. However, in order to acquire good modeling techniques more tutorials and experiences are necessary.

Specifically, Visual Nastran "getting started" contains the following general Finite Element Analysis (FEA) tutorials: FEA Overview, Generate FEA Results, Play the Results, Show the Results, Interpret the Results, Improve the Results, Improve the Analysis, and Improve the Model. On the other hand, the tutorials being developed are more specific. They will help students to better understand different physical behaviors and the physical behavior of the various elements available for use; to determine the appropriateness of one-, two-, or three- dimensional idealizations; to help choose the proper type of element or elements to match the physical behavior of the problem; to better understand boundary conditions imposed; to better determine the kinds of loads that must be applied and their magnitudes and locations (i.e. concentrated or point loads); to better understand the use of symmetry; to better determine sizing of elements and mesh refinement, etc. Furthermore, tutorials with different types of analysis will be presented including stress, vibration, buckling, and thermal study cases.

FACULTY DEVELOPMENT TOOLBOX
A faculty development resource called the toolbox (www.engr.panam.edu/~toolbox) has been created to assist in the development of asynchronous computer-based training materials and as a repository for developed materials. In addition, the toolbox has other resources for using

technology in the development of educational materials. The toolbox contains samples of materials that have been developed including detailed explanations of how those materials were developed. The sample material may be downloaded and incorporated into a course or modified to teach other course content. The toolbox contains numerous examples of screen capture movies for teaching engineering software and resources for developers who wish to create instructional movies.

CONCLUSIONS

The use of "screen capture with audio" AVI tutorials provides a very effective mode in which to deliver asynchronous instruction of math and engineering software. The students have indicated that they feel that the asynchronous materials not only help them complete assignments in a timely fashion, but also help them better understand course concepts. In fact they are upset when the material development does not keep pace with the class. The technique has been successfully used in a number of engineering courses. Its use continues to be developed for other courses in the curriculum that make heavy use of math and engineering software. It is expected that the theory and fundamentals taught, along with the computer based training, will better prepare our students for the demands of industry and graduate school.

REFERENCES

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