AC 2008-1735: IT-ENHANCED TEACHING AND LEARNING IN MACHINE DYNAMICS

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IT-Enhanced Teaching and Learning in Machine Dynamics

Abstract

Challenging problems of modern engineering education, teaching and learning methods are still mostly based on traditional lectures and exercises, which fall short in their efforts to develop the engineering skills levels of today's engineers. Information Technology (IT) can play a significant role in the development learning environments and lead students through the processes of structuring of information into knowledge.

The integration of IT into the classroom provides innovative learning environments that allow for more interactive, relevant, and effective applications to give students experiences through simulations of physical systems. This paper presents a means to enhance teaching and learning experiences through the use of IT in a course on mechanisms and machine dynamics. Through the use of virtual collaborative environments, virtual laboratories, software for simulation and visualization of mechanical systems, and web-based multimedia modules, students are given a chance to experiment with ideas and see the results of their efforts on the computer's screen. In this approach, the instructional material is presented on the computer with the conceptual elements explained and supplemented by the instructor's lecture. Then, a laboratory exercise is executed on which involves combinations of virtual and real representations under the supervision of the instructor to give experience in application of the concepts. Initial student feedback has shown that this approach allows students to augment their learning over and above the level obtained through conventional classroom setting.

Keywords: Engineering education, Machine dynamics, Information technology, Virtual learning environments

1. Introduction

Today in the era of information explosion, engineering faculty members^{1,2,3} are concerned that their students do not receive enough practical knowledge of engineering. The traditional education approaches are generally instructor-centered, where the instructor controls the material and pace of learning. The instructor introduces a topic by lecturing on general principles, then uses the principles to derive mathematical models, shows illustrative applications of the models, gives students practice in similar derivations and applications in homework, and finally tests their ability to do the same sort of thing on exams.⁴ Beyond the course textbook, the information sources are the school library, as the primary medium, and the laboratory. As engineering schools experience increased competitive pressures in maintaining students numbers and teaching quality, IT is becoming the key driver that schools should explore to improve educational environments and find better pedagogical methods to cope with these challenges.⁵

IT is changing the ways in which course contents are presented and delivered to students. It is opening new pathways to knowledge and delivery of services to support the learning/teaching process. It allows instructors to model learning strategies and allows individual students to approach tasks in different ways using different strategies. For example, WebCT (Web Course

Tools) is one of the latest waves of technology-based pedagogical tools⁶ to support Web-based learning (E-Learning). In WebCT, an instructor can use the Designer, Options, and View tools of the predefined website design to construct and organize the course without the need of any web-development packages (Java, html, JavaScript, etc.). The instructor simply adds the predefined tools (lectures, assignments, laboratories, quizzes, etc.) that should be available for the particular course. Students can have access to course content at any time and from any convenient location. Students are able to retrieve information from the WebCT live in the classes, and are able to use those effectively in classroom presentations. The use of the WebCT has led to substantial reduction in information overload on the instructors and students. Additionally, it enables students to have increased access to and use of a wide range of information, allowing for greater inquiry and investigation, exposure to places and resources beyond the classroom, and development of a stronger knowledge base. Capabilities such as online assessment, simulations, multimedia, and any other form of access to external resources provide potential advantages over lecture-only classes.

Currently, there are a lot of simulation and animation packages in use, and some of them are developed for educational purposes to illustrate complex mathematical relationships and physical phenomena. CD-ROMs, web-based tools, and desktop computer game simulations are also used to support learning through real-world problems and provide methods to enhance the traditional learning process and address multiple learning styles. Furthermore, they give the students additional insight into problems during classroom teaching as well as in the individual study process at home. For example, a set of computer programs to accompany a kinematics textbook^{7,8} were developed as a virtual learning environment. In this set, there are many helpful analyses and animation programs for linkages, gear trains and cams, which allow the students to visualize the motions of these mechanisms using realistic models. Software packages such as Working Model⁹, LINCAGES¹⁰, and SAM¹¹ are available for the analysis and synthesis of planar and spatial mechanisms. With the help of those software packages, a student can sketch a mechanism using a variety of simple geometric primitives and add various constraints (joints, springs, and dampers) and actuators (cylinders and motors). With a click of a mouse button, the student can analyze the mechanism and animate the motion. Linking complex theory and equations to numerical and animated graphical results increases understanding and information retention and decreases the traditional trial and error effort associated with mechanism design.

The emergence of the Internet and World Wide Web as a viable means of IT for re-use of education materials fundamentally changed our view of the way education and learning can be delivered.¹² A web-based application allows the previously identified concepts to be put in practice and reach more students with specialized instruction and self-paced learning.^{13,14} Poindexter and Hek¹⁵ described that the integration of the Internet with education can be based on the following: developing a course Web-site to centrally house various online functions and facilitate course management, modeling and demonstrating of current theories and practices to run online during class time, establishing online assessment tools and databases, creating a virtual laboratory in which animation and simulation replace physical experiments and developing a remote laboratory that enables students to set up the parameters that run an experiment from a remote location using the Web. Dealing with this matter, SoftIntegration Inc.¹⁶ developed a Web-based interactive mechanism analysis and design system to provide the students with a convenient means to quickly obtain solutions to many mechanism design problems. A student laboratory approach based on remotely accessible experimental setups was

developed and piloted at Stevens Institute of Technology (SIT) to support a junior-level course on mechanisms and machine dynamics for mechanical engineering majors. Details of the methods and software modules used to implement remote and virtual experiments in the Web-based integrating system can be found in references.^{17,18,19,20} Stevens Online Laboratory Environments²¹ (SOLE) include both remotely operated experiments based on actual experimental devices and virtual experiments based on software simulations. Also, SOLE facilitates the development of learning environments, which in conjunction with traditional hands-on experiments – allow the expansion of the scope of the students’ laboratory experience well beyond the confines of what would be feasible in the context of traditional laboratories.

For the reasons stated above, SIT has implemented a new undergraduate engineering curriculum that reflects the latest trend towards enhancement of traditional lecture-based courses with both a design spine and a laboratory experience propagating through the entire educational program to expand educational opportunities for a larger number of students. Use of such tools can promote collaborative learning, enhance critical thinking skills and give every student an equal opportunity to participate in classroom discussions. Dealing with this matter, the paper presents a means to enhance student learning experiences in the mechanisms and machine dynamics course through the use of information technology.

2. Course Description

ME358 (mechanisms and machine dynamics) is a required junior level mechanical engineering class at SIT. It requires three 50-minute lectures and a 2-hour lab per week for a total of three academic credits. It is designed to provide the mechanical engineering student’s background in kinematic synthesis and analysis, the tools necessary for kinematic and dynamic analysis of mechanisms and machines, and the skills necessary to consider the role of dynamics in the design of machines. Comparing with the previous offerings of this course, the use of IT provides the means to shift the course toward a highly visual orientation and use computational techniques to solve real-world engineering problems.

Traditionally, many of the concepts and numerical methods used in theory of machines and mechanisms are taught in a classroom-based lecture. Most classroom teaching methods depend heavily on blackboard drawings of linkages and various geometric constructions related to the linkages²². Redrawing a linkage in the next position is time-consuming and confusing. A typical course requires the students to formulate the equations governing the kinematics and dynamics of some simple mechanisms, decide on the known and unknown parameters in an organized way, solve these using algebraic techniques, sketch a graphical solution for position and possibly construct a cardboard or stick model. Even if physical models are used to build mechanisms and illustrate the motion, the link lengths of these models will be fixed to some extent, and the physical models can not represent the rest majority of options closely. Therefore, the students are not able to easily visualize many of the kinematic and dynamic alternatives and concepts. They do not always acquire an intuitive feel for the dynamic behavior of linkages. The only advantage of using the traditional approach is that it permits the student to get a handle on the formulation that forms the basis for the analysis of a simple mechanism. On the other hand, they lack a complete understanding of the motion of the mechanisms and their manifestations. It should also be noted that, synthesis of mechanical linkages that achieve a specific output motion with a

specific input motion, called function generation, requires either tedious, iterative methods or the use of advanced mathematics such as nonlinear equation solvers and complex number methods²³.

Our goal is to integrate the virtual learning environments into the traditional approach so that the student can derive benefits from both. Integrating software tools into ME358 allows a student to develop a personal computer lab in which a mechanism or a machine can be animated; velocities, accelerations and forces can be plotted; and parameters can be varied. It opens an opportunity to study a variety of mechanisms, obtain quick results, and compare many possibilities prior to selecting the best mechanism through the detailed visualization of virtual mechanisms. It gives the student a better understanding of the motion, the path of a specific point, and the functionality of the mechanism. It thus brings another dimension to their experience-the 'feeling' of the design, and provides an efficient way of involving students in the active learning process.

3. Features of the Course

The course contents were designed to strongly emphasize the integration of computer programs with traditional hand computational methods to provide multiple exposures of computer analysis in the mechanism synthesis, as shown in Figure 1. In addition, the course instruction used to help students organize the knowledge, some learning activities should challenge them to select, identify, and defend their choices of concepts and principles for use in a given context. Dealing with this matter, many modifications have been made and new features have been added since fall 2007 semester.

Figure 1: Features of the mechanisms and machine dynamics course

The Design of Machinery textbook by Robert Norton⁷ was chosen to emphasize both the use of manual computational methods and computer software to solve mechanisms analysis problems. The textbook has an attached DVD containing linkage design and analysis computer programs such as FOURBAR, SLIDER, DYNACAM, and ENGINE. These computer programs are developed based on the mathematics derived in the textbook and used the equations presented therein to solve for position, velocity, acceleration, and force in linkages of the variety described in the particular program's name. Students use these programs to perform parametric analyses related to textbook problem assignments and tests. Worksheets for equation-solving software such as MathCAD, MATLAB, TKSolver along with Working Model[®] for visualization have

also been used to supplement the mechanisms and dynamics course. The course has been organized using WebCT. WebCT is a tool that facilitates the creation of World Wide Web-based educational environments to expand the teaching capabilities. It provides a set of educational tools to facilitate learning, communication and collaboration. Using WebCT with the course, it forces students use the computer as a natural tool in their problem solving activities. All course lectures are supplemented by the use of electronic slide presentations and are made available to students through the WebCT with links to additional asynchronous tutorial materials as appropriate.

Laboratory experience is facilitated through a combination of virtual and remotely accessible experiments. A student laboratory approach based on remotely accessible experimental setups was developed and piloted at SIT. The various virtual and remote experiments that are currently available in this online laboratory can be used through the corresponding homepage.¹⁷ These Web-based tools integrate both remotely operated experiments based on actual devices and virtual experiments representing software simulations.

All of the above processes allow students to move from passive to active learning and from dependence to independence. Active learning²⁴ is a process whereby students engage in higher-order thinking tasks such as analysis, synthesis, and evaluation. Cooperative learning, problem-based learning, and the use of case methods and simulations are some approaches that promote active learning. The following sections briefly describe these interactive learning modules to integrate active learning into the classroom of the machine dynamics course.

3.1 Problem-based learning (PBL)

PBL is a way of designing and conducting educational activities using problems as stimulus and focus for student activity. It is the classroom process that uses “real-world” problems to motivate students to identify and apply concepts, principles and information. It is intended to bridge the gap between a theoretical study of kinematics and the application to practical mechanisms. In this way, students should learn how to apply their basic knowledge to more realistic applications in a way that they may be able to engage in industrial applications. Computer model based simulation uses embedded relationships between various parts of the system and can exhibit a correct motion, kinematic, and dynamic behavior of a physical system. These computer programs help the student to understand deeply, and in a more visual way, the theoretical basis explained during the lectures. At the end every chapter, students are required to find out at least one case study to illustrate a mechanism that is used on industrial equipment and challenge students to discuss the rationale behind the design. The following section gives examples of engineering case studies used in this course to illustrate the structured learning process:

3.1.1 Car suspension system

For better understanding of the theoretical concept of the mechanisms in a more visual way, the design example is presented to the student at the lecture as a real-world application that uses the fourbar mechanism. For example, students learn in class that most car suspension mechanisms are either fourbar linkages or fourbar slider-crank with the wheel assembly carried on the coupler. The fourbar suspension system has two basic functions to keep the car's wheels in firm contact with the road to provide traction and to provide a comfortable ride for the passengers and

isolate them from road noise, bumps and vibrations. Course WebCT offers students link to the available resources on the World Wide Web, students seek information about car suspension system to figure out the operational characteristics, dimensions, and kinematic diagram, as shown in Figure 2-a. Students are required to entirely build the kinematic performance of the fourbar suspension system by the positions of the pivots; the shapes, sizes, material properties, etc. of the links themselves have no effect. To start with the kinematic analyses, the student has to enter the linkage parameters to the FOURBAR program.

Figure 2: Kinematic and dynamic analysis of the car suspension system

FOURBAR program⁷ is used to analyze the kinematics and dynamics of this type of linkages and evaluate it based on various criteria, as shown in Figure 2-b. It can simulate the motion of a linkage, and display specific linkage analysis functions such as transmission angle, angular velocity ratios, locations of instantaneous centers of rotation, and mechanical advantage (static forces which can be compared to the dynamic force calculations). Once the kinematic model of the car suspension system has been built up in the FOURBAR program, the model is simulated to determine the suspension kinematics and view the path of the instant center over some range of motion to provide a clear picture of the behavior of the coupler link. Also, the motion parameters can be easily changed to visualize such output motions as displacement, velocity and acceleration in a form that is easily understood. In this manner, the software does not become a black box because students understand the theory and know what the software is doing. This approach speeds the student’s progress so that there is ample time in a semester for other worthwhile activities.

3.1.2 Cam-follower system

In class of machinery in which accurate timing is paramount, the cam is an essential part of mechanism. Students learn in class that the use of cam-follower system is vital in engines, where it is used to open and close the inlet valve and the exhaust valve to the cylinder head, as shown in Figure 3-a. The DYNACAM program afforded the students the ability to create two-dimensional model of cam-follower mechanism that functioned like real mechanisms in terms of their motion. It has built-in numerical analysis functionality (modified trapezoidal, modified sine, cycloidal, etc.) that is used to automatically generate derivatives of the follower displacement corresponding to follower velocity, acceleration, and jerk, as shown in Figure 3-b. General polynomial functions can also be designed using any set of boundary conditions to create custom cams that use multiple, single, or no dwells. Then, the cam profile is calculated and a cutter-coordinate file can be exported in either Cartesian or polar coordinates in a form that can be imported into Excel and CAD packages. The program also gave the students the ability to make changes to the dimensional aspects of the model and observe the effects immediately to a good final design. All calculated kinematic and dynamic parameters can be plotted, and all data may be printed to the screen, to a printer, or to a disk file suitable for import to a spreadsheet program.

Figure 3: Kinematic and dynamic analysis of the cam-follower mechanism

3.1.3 Slider-crank system

The previous examples have introduced kinematic synthesis of planar mechanical systems and analysis techniques for the determination of dynamic forces, moments, and torque in machinery.

In this context, it may also be useful to expose students to integrate all these dynamic considerations into the design of a common device, the slider-crank linkage as used in the internal combustion engine. The ENGINE program is used to solve the kinematic and dynamic equations for the slider-crank linkage as used in the internal combustion engine, as shown in Figure 4-a. A pressure curve that represents the gas explosion is built into the ENGINE program to simulate that event. The student needs only to input the stroke volume of one cylinder, the crank and conrod lengths, and the masses and locations of the centers of gravity of crank and conrod to calculate all kinematic and dynamic parameters for an assumed constant angular velocity of the input crank of a one-cylinder, or multi-cylinder inline, vee, opposed, or W engine configuration. The program provided a realistic animation of the motion and the students could readily appreciate the connection between the input torque at the crank and the output motion of the slider. The force, moment, and torque balance configurations are also calculated for any selected engine configuration based on the chosen crankshaft phase angles, number of cylinders, and vee angle(s), as shown in Figure 4-b.

Figure 4: Kinematic and dynamic analysis of the slider-crank mechanism

A side-objective is to introduce the use of MathCAD as a powerful software tool in programming analysis equations. Once the mathematical model has been evaluated, students are asked to interpret and verify their results by working with the actual linkage.

3.2 Experiential learning

In experiential learning, the instructor is providing some motivation to help students have a real experience as a starting point for learning. Students act and think to integrate real experience,

reflection, generalization (abstract conceptualizations), and experimentations. Students can gain the same hands-on experience through online laboratories as they would by physically attending a lab²⁵. The laboratory associated with this course seeks to reinforce students in class concepts as well as expose students to the experimental techniques related to system analysis. Laboratories performed in this course are shown in Table 1. In each laboratory students are first asked to develop computer simulation of the systems to be studied and then to compare predicted with measured results.

Table 1: Mechanisms and machine dynamics laboratories

Week	Lab	Tools	Lab Type	Assignments
1	Graphical Linkage Synthesis	FOURBAR Program	Simulation	Handout
2	Straight-line linkage	FOURBAR Program	Simulation	Read Chapter 3
3	Three position analysis	FOURBAR Program	Simulation	Read Chapter 5
4	Cam Design	DYNACAM Program	Simulation	Read Chapter 8
5	Gear Ratio Measurement	Industrial Emulator experiment at: http://remlab.me.stevens-tech.edu/website/	Remote / Simulation	Handout
6	Inertia Measurement	Industrial Emulator experiment at: http://remlab.me.stevens-tech.edu/website/	Remote / Simulation	Handout
7	Free Vibration with Initial Displacement	Remote Lab Website at: http://remlab.me.stevens-tech.edu/website/	Remote / Simulation	Handout
8	Step Response	Remote Lab Website at: http://remlab.me.stevens-tech.edu/website/	Remote / Simulation /	Handout
9	Industrial Emulator	Game-based laboratory	Game	Handout

3.2.1 Straight-line mechanism

In kinematics, the main interest has been to use fourbar linkages to generate curves by converting the circular motion of the driver link to other types of motions. For example, students are introduced to straight-line mechanisms that convert rotary motion into an approximate or exact straight-line motion such as the Peaucellier-Lipkin, the Hoekens, the Chebyshev and the Watt linkages. In the laboratory, each group of students is selecting one mechanism from a selection of those capable of producing straight-line motion, and find the real-world applications that are using these mechanisms. Course WebCT offers students link to the available resources on the World Wide Web for design and analysis of various planar mechanisms and the search tool to easily find topics within the course. One of those resources, the Cornell's KMODDL (Kinematic Models for Design Digital Library) Web site²⁶ is a rich resource to show students such practical applications. It is an online multimedia representation of the machines along with digitized books and other information on the history and theory of machines. This digital library contains four types of learning modules including textual materials, QuickTime virtual reality movies, Java simulations, and stereo-lithographic (STL) files of the physical models. For example, students can visit the collection (Cornell's KMODDL) and seek information about Watt's linkage. This

mechanism is used in the rear axle of a car suspension to prevent relative sideway motion between the axle and body of the car, as shown in Figure 5. Students then can use the FOURBAR program to perform parametric analyses related to assignments and build a dynamic simulation model.

Figure 5: Watt straight-line linkage analysis

3.2.2 Online laboratories

One of the prominent advantages of online laboratories is their flexibility of delivery. The Web page at <http://remlab.me.stevens-tech.edu/website/> that hosts a combination of both remote experiments based on hardware setups and virtual experiments based on software simulations has been developed and integrated into the mechanisms and machine dynamics course, as shown in Figure 6. As shown in Table 1, ME 358 offers two experimental systems over the Internet: the vibration systems where students can remotely run a one degree of freedom spring–mass–damper system to measure the free vibration with initial displacement, forced vibration with step input and frequency response with sinusoidal input and Industrial Emulator System to measure gear ratio and inertia for the drive disk with rigid/flexible belt. The remote experiments were designed to be conducted in batch mode, where first the experimental input provided by the students is placed in a file. Then, the experimental stations (consisting of the experimental device that is controlled by a LabVIEW running on a PC equipped with a data acquisition board) execute the experimental procedures according to the students' input. Finally, the experimental results (including data in text and graphical form as well as video recordings of the experiments) are stored in a searchable database. The software based virtual experiments are similarly accessed through a web browser. The applications enable the students to change a variety of input parameters, resulting in an immediate change in the corresponding experimental results. The flexibility of these simulations allows for changes in the parameters that might not otherwise be

possible or feasible with physical setups. These simulations also provide for 3-D models, where students can interactively manipulate the camera or point of view.

Figure 6: Remote and virtual experiments for the ME358 course

3.3 Team-based learning

In this mode, one employs a group of teaching/learning techniques where students interact with each other to acquire and practice the elements of a subject matter and to meet common learning goals. Today's students have knowledge and skills from extensive use of computer and video games. Taking advantage of this positive attitude, we can utilize an existing game engine as a means for creating educational tools that will make it easier for students to learn in an engaging manner. A multiplayer game mode can thus be employed to enable multiple students to participate in a collaborative laboratory session.

3.3.1 Game-based laboratory

The game-based laboratory was tested in the fall semester of 2007. The game engine with all the files necessary to run the main part of the game has been installed onto three computers at different places on campus. The students are grouped in teams of 3 to 4. They log on the same time from these different locations to perform the collaborative experiment. They are visible in the virtual laboratory space as avatar-based characters, as shown in Figure 7. The names of all students are visible to the other students in the corresponding groups. The laboratory assignment for the laboratory exercise using this industrial emulator involves the following: (a) assembling of mechanism in right logical order according to a manual, (b) running experiments with/without weights on the disks and rigid/flexible belt, (c) analyzing experimental results, and (e) writing report. Based on the laboratory instructions, the students negotiate the division of the tasks amongst themselves using the integrated communication features (e.g. instant messaging, voice/video, etc.). Upon completion of the set-up tasks; the developed linking tools collect all the set-up data and automatically launch an input/output menu to carry out the remote experiment or

the virtual experiment. Then, the students obtain and analyze the results and prepare the laboratory report. A post-test is given to each student to assess learning outcomes.

Figure 7: Game-based laboratory environments

A combination of these approaches is the outcome of a student-centered classroom process that uses real work problems as well as fictitious scenarios to motivate students to perform or act out the discovery and application of concepts and information. Students develop familiarity as well as formal understanding of the course content. The cooperative team-based learning aspect supports teambuilding skills outcomes and holds all students equally accountable to syllabus requirements.

4. Course Assessment

For the course as a whole, as well as for each laboratory module, a list of key principles and learning objectives is developed. At the end of the course, evaluation form with a series of detailed written questions to assess the effectiveness of the course in teaching the key principles, as shown in Table 2, are distributed to students. The survey consists of asking the students to rank their skills and abilities supporting each of the ten course outcomes and four laboratory outcomes using the following 5-point scale:

5. Great learning experience
4. Significant learning experience
3. Some new learning
2. Little new learning
1. No new learning

Numerical values greater than the mid-point value are considered as positive attitudes expressed by the students and those less than the mid-point value as negative attitudes. The outcome of this survey (see Table 2) indicates that the students were strongly satisfied with what they learned in understanding the fundamental concepts and principles of mechanisms and in practicing experimental skills. Specially, questions 8 to 9 are to evaluate the use of computer programs to perform parametric analyses related to textbook problem assignments and tests. The students gave very positive feedback, which indicates that they were very satisfied on the use of the computer programs to help with analysis and visualization of the motion of mechanisms. Also, the results of the laboratory survey indicate that the students had a positive laboratory experience.

Table 2: Course and laboratory outcomes

	key principles	5	4	3	2	1	Average
Course outcome	1. You are able to apply the basic kinematic concepts to analyze rigid body motion	4	7	2	0	0	4.15
	2. You are able to synthesize a linkage mechanism for prescribed motion, path or function	6	5	2	0	0	4.31
	3. You are able to synthesize cam profiles for desired follower motions	7	6	0	0	0	4.54
	4. You are able to develop a kinematic and kinetic model of real-world mechanisms	6	5	2	0	0	4.31
	5. You are able to develop a kinematic and kinetic model of real-world mechanisms	4	6	3	0	0	4.08
	6. You are able to synthesize basic gear trains for desired rotational output	7	4	2	0	0	4.38
	7. You are able to formulate and solve mechanism analysis and synthesis problems, through the use of manual and computer program	4	8	1	0	0	4.23
	8. You are able to use interactive PC-based computer programs (included in DVD that comes with the textbook) to analyze and design linkages and cams	10	3	0	0	0	4.77
	9. You are able to use interactive PC-based computer programs (included in DVD that comes with the textbook) to visualize machine motions	10	2	1	0	0	4.69
	10. You are able to implement Game-based learning environment as “Effective team work skills”	3	5	4	1	0	3.77
Laboratory outcome	1. You are able to generate a specific path of motion of a linkage in the simulation-based laboratory	6	6	1	0	0	4.38
	2. You are able to model in the simulation-based laboratory a cam-follower mechanism that functions like a real mechanism in terms of its motion	7	4	2	0	0	4.38
	3. You are able to measure the gear ratio and inertia of the emulator system in virtual and remote laboratory	8	1	4	0	0	4.31
	4. You are able to analyze the vibrational behavior of machines in virtual and remote laboratory	7	3	3	0	0	4.31

5. Conclusions

Computer-based techniques have been proven to serve as excellent teaching aides that are greatly enhancing the teaching and learning processes in mechanisms and machine dynamics. They allow for a deeper exploration of a complex issue or concept with greater student involvement and enjoyment. Students learn better when presented with a visual model. By using simulations to enhance traditional teaching and learning, students are given an opportunity to participate in active learning. They can perform a wide range of exercises within a computer-based learning environment. The feedback evaluations of the students relating to the effectiveness of the integration of IT tools into the classroom were overwhelmingly positive. Students strongly agreed that it was easy to figure out how to use the simulation tools to visualize the motion of

mechanisms. They strongly agreed that the overall class experience was enhanced by the use of information technology and the Internet. In addition, improvements were realized in quality of teaching and learning through the facilitation of access to educational resources and services, as well as remote exchanges and collaboration. Students indicated that they would like to see use of these techniques in other classes as well.

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