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THE DEVELOPMENT OF A DYNAMIC SYSTEMS LABORATORY AND THE IMPLENTATION OF LEARNING-THROUGH-TEACHING CONCEPT

Chiang Shih, Patrick Hollis, and George Buzyna
Department of Mechanical Engineering
FAMU-FSU College of Engineering
Florida A&M University and Florida State University

Abstract

A full-scale dynamics laboratory was developed to enhance hands-on experience and foster strong faculty-student interaction in the teaching of the Dynamic Systems classes. To emphasize the “seeing is believing” concept, we have also designed visualization-based courseware to supplement the regular lecture teaching. In addition, the dynamics laboratory facility has also been used to familiarize students with experimental techniques and data acquisition systems useful in developing design projects with greater scope, hence strengthening the design component of the Dynamic Systems discipline. We have also implemented a "**Learning-Through-Teaching (L-T-T)**" concept to encourage the active participation of all students. The implementation of the L-T-T concept helped students to achieve a deeper understanding of the subject by being involved in the teaching process. In addition, the concept can enhance full collaboration between faculty and students and among students themselves to make the classroom a truly cooperative learning community. Although the L-T-T concept is still in the developing stage, its success has convinced one of the authors, Chiang Shih, to apply the concept to other classes at different levels. Based on preliminary assessment, it is believed that a more coherent implementation, both vertically throughout the curriculum and horizontally across all disciplines, can greatly improve educational experience of engineering students.

Introduction

Dynamic Systems courses are among the most difficult classes for undergraduate engineering students. One of the major reasons is that it is difficult to conceptually visualize motion in dynamic processes. In addition, some physical concepts in dynamic systems, such as a disk rolling without slipping, are actually counter-intuitive and can confuse first-time students. Therefore, visualization methods can play an important role in the study of dynamic processes because "*seeing is believing*." The understanding of the fundamentals of dynamic systems can

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be greatly enhanced if motion in these systems can be captured using digital image recording and processing techniques. The *"seeing is believing"* concept is well known to be effective since most students are visual learners and they get more information from visual images than from verbal materials (Barbe and Milone 1981). In particular, educators from the Air Force Academy and the University of Colorado (Borchert et. al. 1999) have developed hands-on and visualization modules for Engineering Mechanics classes. Their results show that the use of these modules indeed enhances the overall learning experience of their students.

In general, it is recognized that there is not sufficient hands-on experience and interaction, other than computer usage, in the teaching of engineering courses. The enhancement of the laboratory experience has been identified as a first priority for the improvement of such courses. In consideration of these concerns, we developed a visualization-based multimedia studio in which **"active examples**", "**hands-on demonstrations**" and a "**full scale laboratory**" have been established. In addition to providing hands-on laboratory practice, the dynamic systems facility has also been used to familiarize students with experimental techniques and data acquisition systems useful in developing design projects with greater scope, hence strengthening the design component of the Dynamic Systems discipline.

We have implemented a "**learning through teaching**" concept to encourage the active participation of all students and to cultivate their higher-level learning skills. Educators from the University of Pittsburgh (Bidanda and Billo 1995) adopted similar concept by using students to develop engineering laboratories. However, their scope of implementation is limited to laboratory development. The L-T-T concept has been implemented with success by educators from North Carolina A&T State University (Pai et. al. 1999). They designed a vertically integrated learning experience, where experienced (upper-level class) students can assist less-experienced (lower-level class) students how to use progressively more sophisticated software packages throughout the curriculum. We would like to combine their experience to include the *learning through teaching* component in our class and laboratory practice. Students will be asked to be involved in the laboratory preparation as well as participation in the actual teaching to their classmates. Currently, this concept is still in the developing stage and has been applied by one of the authors, Chiang Shih, to other classes at different levels with noticeable success. It is believed that a more coherent implementation, both vertically throughout the curriculum and horizontally across all disciplines, can greatly improve educational experience of engineering students.

Laboratory development

In order to make the laboratory participation a true learning experience, the visualization courseware has to be not only visually appealing but also quantitative and interactive-capable. Three types of delivery have been developed: **active examples** designed to enhance the regular lecture teaching; **hands-on demonstrations** for extensive use during the 3-hour weekly workshop period; and a **full-scale dynamics laboratory**. This three-prong pedagogical approach provides a systematic integration of the visualization courseware into the teaching of dynamics courses and will be described in the following:

Active Examples (AE): Traditional lecture teaching frequently involves the use of classroom examples to present key concepts. A typical sample problem usually consists only of a problem statement accompanied by a schematic sketch. This type of "passive" presentation is preferred not because it is effective but because it is convenient. In this project, we are proposing to change that by injecting life into these examples using real objects instead of abstract schematics. A combination of still images and animation sequences of the system in motion will be digitally recorded and processed to accompany each problem. For example, an actual piston-crank mechanism is used to demonstrate the relative motion between rigid bodies. The animated sequence of the motion of the linkage between the piston and the rotating crank clearly shows the general planar motion of a rigid body involving both the translational and rotational components. Frame by frame digitization of positions of selected points on the mechanism are used to provide relative motion data to be compared quantitatively with the theoretical values. Instead of looking at abstract mathematical symbols such as position and velocity vectors, students now can have a better comprehension of the physical concept of relative motion using this visualization enhancement.

Hands-On Demonstrations (HD): In the Dynamic Systems class, a three-hour weekly workshop is introduced to provide an extended period of time for students to work on actual lab models of typical dynamics problems. The visualization-enhanced courseware is used extensively in the workshop session. First, a live demonstration of either an experiment or a system model is performed in front of all students in addition to a real-time video display that is projected onto a screen. The hands-on experience is provided by supplying a frame-by-frame digital image sequence of the experiment on the Web page. All students are required to process and analyze this digital data in order to complete their projects. Since all information is available over the Web, students are able to read and record data by browsing through these pre-arranged projects at their own pace.

Full Scale Laboratories (FL): No matter how sophisticated a demonstration package maybe, it can not replace real hands-on laboratory experience. However, a well-designed demonstration, functioning as a virtual laboratory can provide useful "pre-lab" experience that greatly shortens students' learning time and makes the operation of the real laboratory more efficient (Scrivener et. al. 1994). Selected hands-on demonstration experiments have been developed into full-scale laboratory experiments, which allow students to participate in a real hands-on laboratory environment. Students are arranged into groups of four to run these experiments. Pre-lab demonstrations are conducted before each laboratory followed by a pre-lab quiz to encourage students' full preparation. Those students who are responsible to set up a particular experiment (see the following learning through teaching section) will be assigned to assist other students in the full-scale laboratory. The instructor and teaching assistants will serve as supervisors to monitor the progress of the laboratory and will be available for questions. It is believed that the use of students to teach other students is not only effective but will also encourage cooperative learning among students. Sample experiments developed in this project are listed in the following table.

Table 1 Dynamic Systems Experiment List

Experiment Topic	Exp. Type	Skills and Concepts Learned
Graphical Analysis of Motion	AE, HD	Graphically determine position, numerically vector calculation

Projectile Motion	AE, HD, FL	Experimental uncertainties, statistical analysis, solving nonlinear equations
Newton's Second Law: Force and Acceleration	HD	Application of motion and force sensors, analog to digital data acquisition, numerical differentiation
Centripetal Force	AE, HD, FL	Numerically relating Cartesian coordinates to curvilinear coordinates
Principle of Work and Energy	AE, HD, FL	Potential energy, differentiation of position, kinetic energy, friction
Two Cart Collision: Conservation of Momentum	AE, HD, FL	Numerical integration of force with respect to time, force sensor for impact
Rotational Collision/angular momentum	FL	Calculate moment of inertia from geometry, angular momentum of a rigid body
Moment of Inertia	AE, HD, FL	Calculate moment of inertia (of composite bodies) from experimental measurements, parallel axis theorem
Conservation of Energy of a Rigid Body	AE, HD, FL	Measurement of angular velocity of rigid body, kinetic energy of rigid bodies
Forced Vibrations	AE, HD, FL	Natural frequency, resonance, mode shapes
Rolling Disk	AE	Rolling without slipping

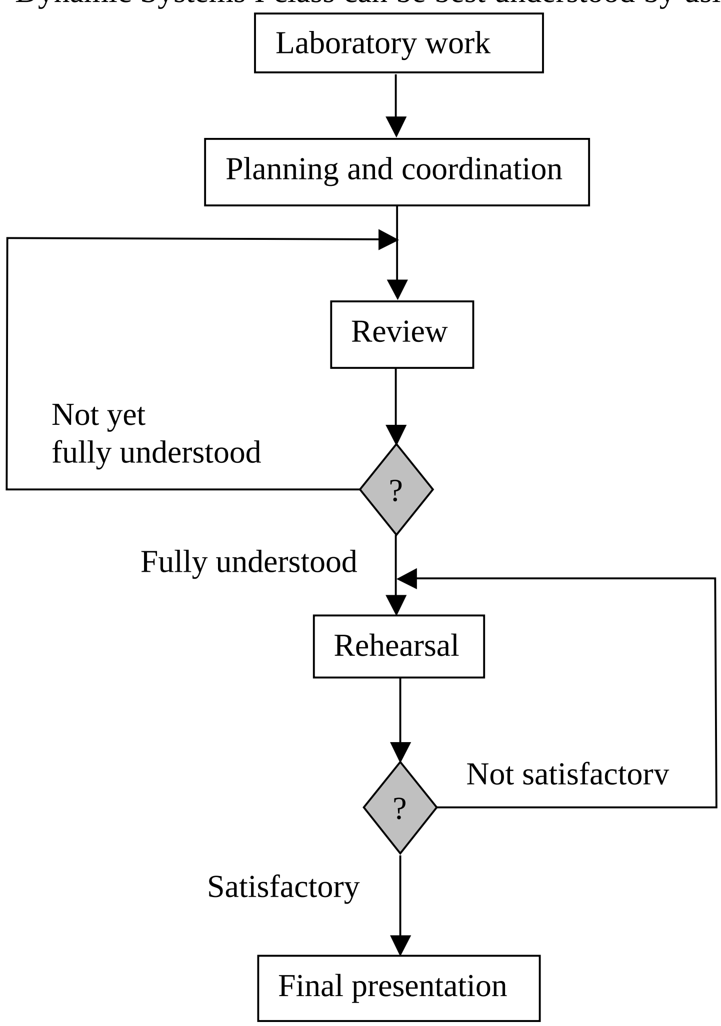
In addition to the enhancement of students' hands-on experience, we methodically introduce many fundamental skills, which are sometimes difficult to present in a conventional classroom setting, into the curriculum. For example, we use frame-by-frame digital images to dissect the motions of various rigid bodies. Traditional vector and Calculus analysis can be exemplified by relating numerical solutions to the analytical theory; statistical concepts can be applied to the estimation of the averaged landing position of a projectile fired from a launcher. Other practices include: the determination of instantaneous velocity and acceleration vectors using numerical differentiation, numerically integrating the impulsive force data to understand the momentum exchange between two colliding bodies, etc. We believe that these seemingly simple exercises can actually provide students with a better understanding of the relationship between the mathematics and the description of physical phenomena. Many of these numerical skills and difficult-to-comprehend concepts are outlined in table 1.

Learning-Through-Teaching (L-T-T) concept

Finally, the unique implementation of the pedagogical concept, learning through teaching**,** will be discussed in the paper. Originally, the concept was designed to serve two purposes: First, it was used to make sure each student will have an adequate hands-on laboratory experience within the limited laboratory period because it is financially impossible to provide multiple experimental stations at this stage. Therefore, hands-on demonstration experiments discussed earlier have to be used instead. Students were asked to be responsible for the complete operation of only one experiment where they can gain valuable experience by fully mastering one experiment. (Note: in addition to the assigned experiment, students have to conduct all other experiments also but at a relatively limited role due to the time constraints). Second, the students for each L-T-T project provide assistance to their fellow students during the workshop sessions. This can encourage strong interaction among students and bring together a true collaborative learning community. Additionally, it has been recognized that this concept can and should be expanded for far greater influence on students' overall education beyond the laboratory experience. Currently, this concept has been adopted by one of the authors (Shih) in other classes and the outcome assessment from these classes will also be discussed.

Application of L-T-T concept in Dynamic Systems I class

The L-T-T concept has been implemented to provide each student with a real "hands-on" teaching experience in a formal classroom setting. Students were assigned into groups of three or four. Each group was assigned a demonstration laboratory and was given two weeks to prepare for the project with assistance from the instructor and teaching assistants. Each groups responsibilities include preparation (information organizing and understanding the relevant physical phenomena), operation (videotaping and image-processing the experiment) and documentation (producing laboratory instruction sheets and Web-publication) of the assigned experiment. Significant assistance was provided at the beginning in order to ensure smooth operation of the demo. However, it was also expected that students might not be able to take over the full responsibility as the project evolved. Finally, students were required to present, in a formal teaching setting, to the whole class using Web-based programs. Their performance was evaluated and the given grade was counted toward their final class grade. The L-T-T cycle in Dynamic Systems I class can be best understood by using the following flow chart.



➢Laboratory work: learning everything about the lab, running the experiment, collection of all necessary data.

➢Planning and coordination: understand theory, finish calculation, organize data into presentable form.

➢Review: data debugging, fact finding with teaching assistants (TA), an iterative process to ensure a clear understanding of the lab by the presenting group.

➢Rehearsal: practice presentation with instructors till satisfaction, another iterative process.

➢Final presentation: present the experiment and assist fellow students with computation and analysis of lab assignments.

Figure 1 Flow chart of the Learning-Through-Teaching process in the Dynamic Systems I course

Students can learn new learning perspectives through the direct participation required by this L-T-T approach since they have been forced to go through the complete teaching preparation process. In the process, they also learned to use image-processing technology, digital data acquisition, Web-authoring and other communication skills. In addition, other students might pay more attention to the presentations made by their fellow students in the expectation that they too will have to do this soon. According to our experience and those of others (Bidanda & Billo 1995), students tend to be more critical of their fellow students as opposed to a faculty instructor, which should lead to more questions and active participation.

Application of L-T-T concept in Propulsion Systems class

The ABET EC2000 accreditation criteria specify a new set of requirements for engineering graduates. Among many traditional attributes, all graduates are now required to establish a recognition of the need for, and an ability to engage in life-long learning. Usually, this aspect is not included explicitly in a regular engineering curriculum and therefore is among the most difficult graduate attributes to demonstrate. To recognize the need for life-long learning, one has to engage in its practice and appreciate its importance to her/his future professional development. According to our personal teaching experience, this practice can best be exercised by learning and comprehending a subject by ourselves and then teach to the students. We faculty have long recognized the importance of this need and applied this concept into our teaching and research activities on a regular basis. That is one of the main reasons why a teacher can usually achieve deeper understanding on the subject she/he teaches than students who have learned from her/him. In consideration of this, the L-T-T has not only been implemented in the development of the dynamic systems laboratory but also in other classes at different levels. For example, Shih has introduced the concept to senior students in one of the technical elective class (Fundamentals of Propulsion Systems). The students are asked to form a small group or as an individual to present a regular one-hour lecture on specified topics to their fellow students. They are also required to report their experience in a final report and publish their findings/presentation on the web. The preliminary assessment result solicited from this group of students (a total of 29 students) shows that a majority of them (79%) either strongly agree or agree that the project is useful in enhancing their overall education. To get a more quantitative measure of their response, a questionnaire concerning the effectiveness of the L-T-T approach was distributed to students at the end of the semester using a response scale from 1 to 5, where 1 represents strongly agree and 5 strongly disagree. The averaged score was 1.55 when students were asked to respond to the following question: *Do you think the learning-through-teaching concept is a good idea and should be implemented throughout the curriculum*? This surely indicates that there is an overwhelming support of the adoption of the L-T-T concept in the class. The following is a list of comments made by students in the survey concerning the L-T-T concept:

- "If students could experience this earlier in their curriculum it might provide more benefits. It will provide the students with the teacher's perspective and in some cases provide more tolerance and understanding on the students' part."

- "We have learned how to take a large amount of information and extract the important concepts."

- “The whole process of gathering information, deciding how to present it and giving a presentation made us have to learn far more than we would have if we were just being taught and tested on the material.”

- “The threat of looking unprepared in front of your classmates as a great motivation.”

- “The learning process is very effective.”

- “We have acquired more confidence that we can teach ourselves a subject. We understand that engineers must continue to learn in order to keep up.”

- “We learn how to do time management.”

- “Implement L-T-T into other course will benefit both students and teachers.”

- “Realize the importance of self-learning.”

It is encouraging to receive this feedback from students since it suggests that they seem to be engaged in some kinds of higher-level learning activities when they were talking about time management, setting boundaries to their project, self-learning, etc. Due to its success, the concept has been applied to other classes such as the experimental class in thermal and fluid science in the Spring 2002 semester.

Summary

Three types of courseware have been developed to supplement the teaching of the Dynamic Systems courses: (1) use of active examples in the regular lecture teaching to replace traditional, lifeless examples; (2) hands-on demonstrations used extensively during the 3-hour weekly workshop period as not only visually-appealing but quantitatively illustrative assignments; (3) a full-scale dynamics laboratory was established to provide students with a comprehensive hands-on laboratory experience. The Dynamic Systems facility has also been used to familiarize students with various experimental techniques and data acquisition systems, which might be useful in developing design projects with greater scope, hence strengthening the design component of the Dynamic Systems discipline.

We have also implemented the "**Learning-Through-Teaching (L-T-T)**" concept to encourage the active participation of all students in the Dynamic Systems class. The adoption of the L-T-T concept assists students in achieving a deeper understanding of the subject by requiring them to participate in the teaching process. The implementation of this L-T-T concept can enhance full collaboration between faculty and students and among students themselves to make the classroom a truly cooperative learning community. Although this concept is still in the developing stage, its limited success has convinced one of the authors, Chiang Shih, to apply the concept to other classes at different levels. Based on preliminary assessment, it is believed that a more coherent implementation, both vertically throughout the curriculum and horizontally across all disciplines, can greatly improve educational experience of engineering students.

It seems to be quite appropriate to conclude our work by quoting from the supplemental instruction literature (Gardiner 1996): "*Tell me and I forget, show me and I remember, involve me and I understand.*" Indeed, the combination of the effective use of visualization-enhanced courseware and the adoption of learning-Through-Teaching concept can assist students in retaining lifelong knowledge and achieving higher level of understanding of the subject. We would like to add one additional statement in summarizing the significance of implementing the L-T-T concept: "*Ask me to teach and I learn*".

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CHIANG SHIH is a Professor of the Department of Mechanical Engineering at the FAMU-FSU College of Engineering. He has received a teaching award for his efforts in the development of the Mechanical Engineering Integrated curriculum. Dr. Shih received his Ph.D. from the Aerospace Engineering Department, University of Southern California in 1988. He is a member of the American Society of Engineering Education.

PATRICK HOLLIS is an Associate Professor of the Department of Mechanical Engineering at the FAMU-FSU College of Engineering. Dr. Hollis received a Ph.D. Degree from the Mechanical Engineering Department, Cornell University in 1986. Dr. Hollis has been the recipient of two teaching awards from FSU.

GEORGE BUZYNA is a Professor of the Department of Mechanical Engineering at the FAMU-FSU College of Engineering. Dr. Buzyna received his Ph.D. from the Engineering and Applied Sciences Department, Yale University in 1967. He is a member of the American Society of Engineering Education.