

INCORPORATING LABORATORY SIMULATIONS INTO NON-LABORATORY COURSES

Edward E. Anderson¹

Abstract *It is well known among engineering educators that it is easier for a student to learn a concept when they can experience it. But, cost of laboratories, safety issues, time constraints, and other factors have reduced experiential components of most engineering curricula, rather than keep it constant or increase it. In the United States, for example, engineering students do not explore or experience the physical world until they have almost completed their programs, and then typically less than 10% of the curriculum is dedicated to these experiences. Integration of computer laboratory simulations into non-laboratory classes offers a means by which this issue may be addressed. How this might be done in an engineering fundamentals course, Introduction to Thermodynamics, is discussed in this paper. Several simulations and their use in lectures, self-study, and assessment of students are presented.*

Index Terms *Computer-based-instruction, computer simulations, laboratory simulations, thermodynamics.*

INTRODUCTION

Today, very little of the application of theory to engineering practice learning is done by “hands-on” laboratory experience. Rather, much of this type of learning is done by presentation, demonstration, modeling, and simulation. Factors, such as cost of developing experiments, operating, and maintaining laboratories, student time constraints, and modeling and simulation improvements, have all contributed to this trend. But, many engineering practices cannot be modelled or simulated, they can only be experienced.

Students often view modeling and simulation as theoretical, not “real world,” efforts. This reduces the credibility of the models and simulations, which interferes with the learning process.

Synchronization of the laboratory experience with the appropriate class material has always been and continues to be a problem. This also interferes with the learning process since the correlation of the theoretical and physical world is difficult to make. This interference can be reduced by repeating the theoretical development at the time of the experiment. But, this may not be an efficient use of the learning time.

In a recent speech [1], Michael Parmentier, Director of Readiness and Training, U.S. Office of the Secretary of

Defense, referred to today’s learners as “The Nintendo Generation” whose first choice for learning is not static text and graphics, but rather is interaction with rich multimedia and simulations. Consequently, the U.S. Department of Defense recently awarded major contracts for the Advanced Distributed Learning project whose goal is to develop systems and standards that better integrate the rather static world of today’s web-based instruction materials with models and real-time simulations.

It is well known that students learn more as they become more engaged with the materials. Reiseman and Carr [6] have concluded that students learn 20% of the material taught by hearing, 40% by seeing and hearing, and 75% by seeing, hearing, and doing. Highly interactive, well-designed computer-based-instruction (CBI) modules then offer the possibility of achieving the 75% goal. Renshaw, et al. [7] state “students unanimously preferred modules that incorporated animations and interactive design tools.” Others [2-5,7,8] have reported similar findings in several engineering fields and topics. Since students prefer interactive multimedia modules and retain more material presented in this way, the goal of any CBI module should be to use interactive engaging material rather than static material.

The challenge is then one of developing laboratory simulations that are simple, relate to the learner’s experience level, and that can be incorporated into and synchronized with other teaching pedagogies. These also need to be structured so that learners can proceed at their pace, receive appropriate feedback and coaching, and can review as often as necessary to master the material. This paper presents and discusses several such simulations that are integrated with a complete CBI system and textbook.

The examples presented are taken from the Introduction to Thermodynamics course that is taught to almost every engineering student. This course is particularly challenging as it is normally taught without a laboratory experience or an experience that appears much later in the curriculum. This course also contains many physical concepts that students are not familiar with. Most of these concepts are easily observed with simple experiments. Therefore, this course is well suited to the use of virtual laboratory experiments integrated with the static elements of the course.

PRESSURE

¹ Edward E. Anderson, Texas Tech University, Department of Mechanical Engineering, & Teaching, Learning and Technology Center, Lubbock, TX 79423-1021, ed.Anderson@ttu.edu
Project sponsored by the U.S. National Science Foundation under CCLI grant 0089410.

The first virtual laboratory experiment considered is one that demonstrates the definition of thermodynamic pressure. The objective of this simulation is to have the student experience the definition of pressure in a static situation as the ratio of the force acting perpendicular to a surface to the surface area itself. The piston-cylinder device shown in Figure 1 was chosen to demonstrate this concept.

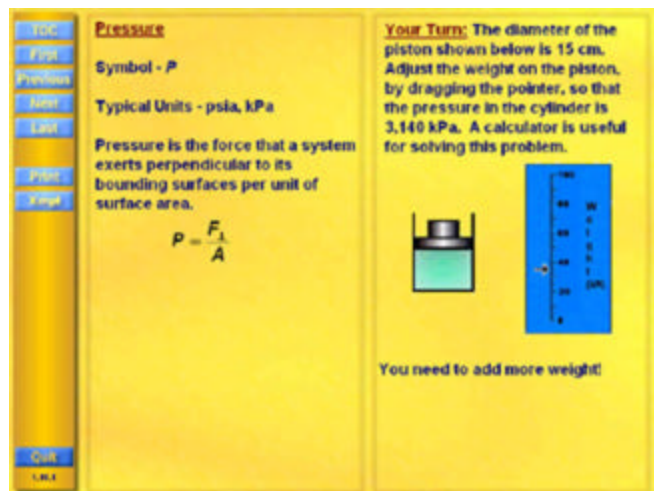


FIGURE 1
SCREEN CAPTURE OF PRESSURE VIRTUAL
EXPERIMENT

This virtual experiment begins by presenting the textual material shown on the left-hand-side of the screen, which summarizes the definition of pressure. The user is then asked to determine the amount of weight that must be placed upon the piston to generate a certain pressure in the piston-cylinder contents. The target pressure is a randomly generated number and users are expected to do an off-line calculation to determine the required weight. The user now proceeds to adjust the arrow slider to the proper weight by dragging it up or down on the scale. Each time they stop dragging the slider, they are informed if they need to add more or remove some weight until they have the proper amount of weight placed on the piston.

This rather simple experiment demonstrates many of the features found in well-designed CBI learning modules. It states the objective, engages the user, allows the user to explore and discover, correlates the information with other sources, provides feedback, may require iteration, and takes advantage of the features found in CBI that are not available in static media. Modules that improve the mastery and retention of knowledge utilizes these as well as other features.

HYDROSTATIC PRESSURE

The objective of this virtual experiment is to have users correlate the hydrostatic pressure equation with physical

reality and to have them observe that only vertical movements change the hydrostatic pressure, not horizontal movements. The virtual scuba diver shown in Figure 2 was selected for this purpose. This particular screen follows two others. The first of these two is a simple textual presentation with an audio voice-over that briefly reviews the theory behind the hydrostatic pressure equation. The second gives further information about the hydrostatic pressure equation and uses a virtual scuba diver that is constrained to vertical motion only. At the point where users enter the screen

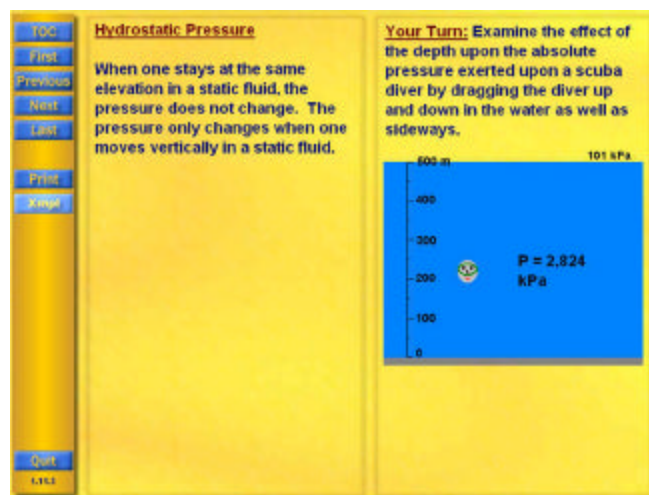


FIGURE 2
SCREEN CAPTURE OF HYDROSTATIC PRESSURE
VIRTUAL EXPERIMENT

This experiment allows the user to move the scuba diver figure about in the water. Both horizontal and vertical movement are permitted. As the diver is dragged about in the water, the pressure gauge reading changes in relation to the depth of the diver. Observe that the depth scale is consistent with the elevation coordinate of the hydrostatic equation so that users will learn to be consistent with the sign convention of this equation. Also, the atmospheric pressure at the atmosphere – water interface is given as a reminder that the hydrostatic equation only calculates pressure differences, not absolute pressures.

Although this example seems to be overly simplistic, the author frequently receives comments from users like “it helps me to understand equations better, when I see how they are applied.” Users also feel that they are better able to retain their knowledge of the hydrostatic equation by interacting with it in this manner versus learning from static text, textbook examples, and homework problems. This is consistent with the findings of Reiseman and Carr [6].

This example also demonstrates the use of coaching as a mean of helping students understand the knowledge being presented. The text above the virtual scuba diver coaches the

student to be sure to drag the diver in a horizontal manner. An accompanying audio voice-over also coaches the student to move the diver horizontally. Properly designed CBI modules have the advantage in that coaching occurs at the time the learner incurs the knowledge, not at a disjoint time, e.g., during a lecture or in the instructor's office. It also has the advantage that the coaching is incurred every time the student views the information like during a review or screen revisit. It is also always applied consistently. Unfortunately, it cannot always be given in direct relationship to the user question like an experienced instructor. But, careful design can overcome this short coming to some degree by anticipating the most commonly asked question or employing artificial intelligence techniques.

MANOMETERS

The final screen of a virtual experiment that demonstrates the operation of a manometer is shown in Figure 3. This experiment is preceded by a short explanation of manometers and the application of the hydrostatic pressure equation to the measurement of pressure. Following this explanation, the screen shown here appears with no pressure being applied in the chamber and hence, the manometer reading is 0 mfluid. The user proceeds to enter a pressure in the text entry box provided. Once this entry is completed, the fluid rises to the correct height in the manometer column as shown here.

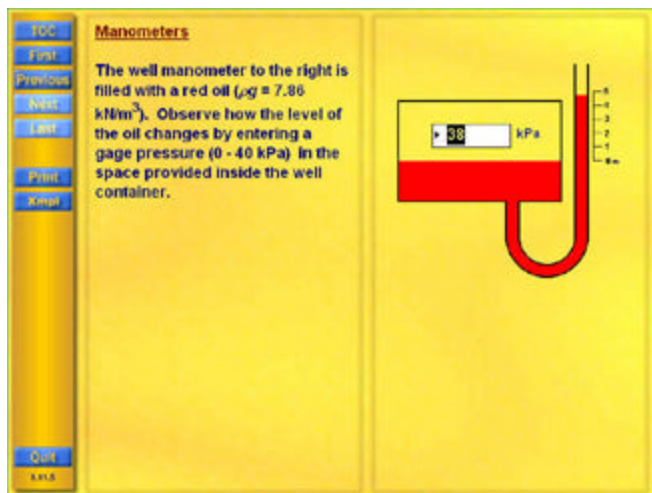


FIGURE 3
FINAL SCREEN OF MANOMETER VIRTUAL
EXPERIMENT

The advantage of this approach to learning how a manometer works as compared to before and after graphics, manometer photographs, videotapes, and other techniques is two-fold. First, there is the motion of the column when the pressure is applied. Second, the user controls the pressure

that is applied and can try a variety of pressures to explore the relationship between pressure and column height. Although videotapes can capture the motion, they do not allow the user to vary the pressure being applied.

Exploration and discovery, like that of this experiment, are known to improve learning since it engages the student in the process, Reiseman and Carr [6], and utilizes their higher order learning skills, Bloom [9]. Also, observe that coaching, in the text, has been used again to add to the effectiveness of the learning process.

PROCESS DEMONSTRATION

This virtual experiment is conducted as a demonstration rather than an interactive experiment. An intermediate screen from the demonstration is shown in Figure 4. The objective of this demonstration is to show the learner the relation between thermodynamic process lines on state diagrams and the physical events that create these lines. An animation of a state point that follows the process line and is synchronized with the motion of a piston is used for this demonstration.

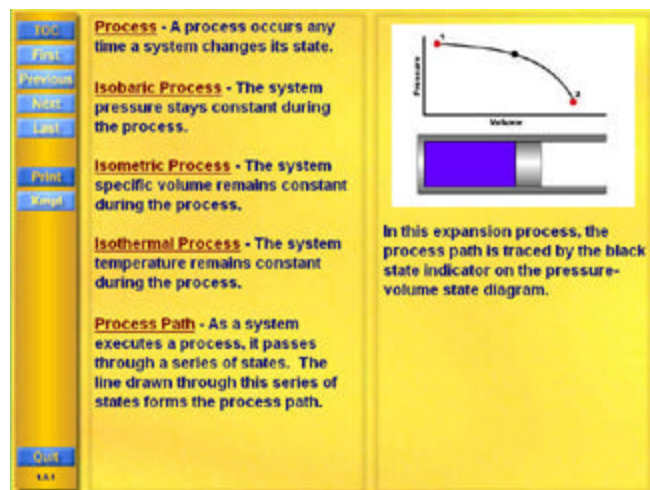


FIGURE 4
THERMODYNAMIC PROCESS LINE
DEMONSTRATION

This screen begins with text and an audio voice-over that discuss the definition of a thermodynamic process, some typical processes, and description of the process path. The animation is then played repeatedly with the synchronized state point tracing the process path. This manner of presenting process paths gives learners a better appreciation of this concept than is possible with static images and text because of the correlation with the physical world of the fluid contained in the piston-cylinder device. Learners also further develop the concept that events occurring during a process are dynamic and involve changing states. They also learn that interactions occur between the thermodynamic

system and its surroundings while a process is being executed, not while the system is static.

PHASE CONVERSION

Although students in introductory thermodynamic courses have a general concept of phases, basically, solid, liquid, and gaseous, they don't have the depth of understanding of phases required for thermodynamic analysis. Phase conversion and the effect of the pressure upon the conversion is a difficult concept to grasp from static descriptive materials. Historically, this concept was experienced in a laboratory experiment or physical demonstration, typically in a chemistry or physics lecture. For the most part, this is no longer done.

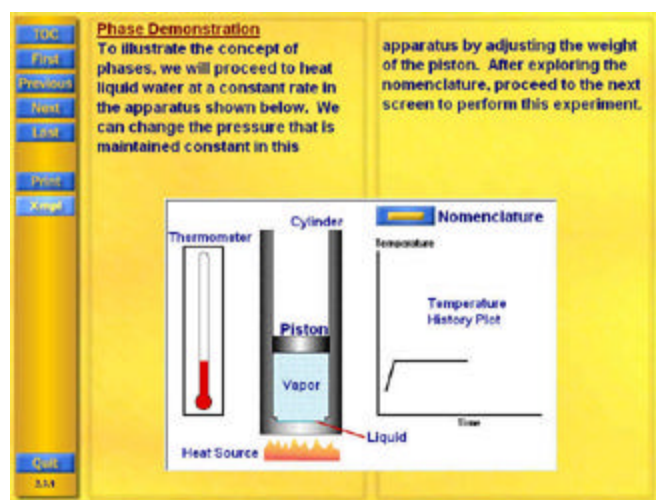


FIGURE 5
FIRST SCREEN OF PHASE CONVERSION
EXPERIMENT

A virtual laboratory experiment that permits the learner to experience the impact of pressure upon liquid-vapor phase conversions begins with the screen illustrated in Figure 5. This screen is accompanied by a coaching audio clip that explains what the learner is about to experience and some comments on what they should be looking for. It also illustrates the nomenclature and correlates the nomenclature with the graphics that are used in the virtual experiments that follow. This nomenclature screen is optional and users can access it by clicking on the nomenclature button.

Following this screen, students select the pressure at which they wish to conduct the experiment. This is done by clicking on the appropriate button shown in Figure 6. An animation simulating the phase conversion at the selected pressure is now played. A typical screen near the middle of this animation is shown in Figure 6. The motion of the piston while the fluid is being heated is directly correlated with the volume of the fluid at that point during the heating.

The thermometer and temperature-time graph are synchronized with the heating process. The isothermal plateau that occurs while the phase is being converted from saturated liquid to saturated vapor is obvious and is seen to occur while the volume of the fluid is changing drastically.

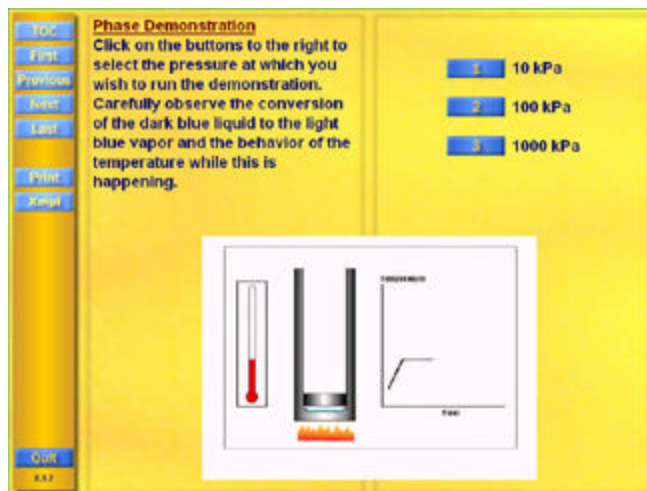


FIGURE 6
PHASE CONVERSION VIRTUAL EXPERIMENT

This simulation may actually be preferred to a physical dynamic experiment. In the laboratory, it is difficult to physically create equilibrium, heat transfer and transient effects make it difficult to observe the isothermal plateau, transparent cylinders typically fog up limiting the visibility of the process, and students lose learning time as they are trained in the operation of the equipment.

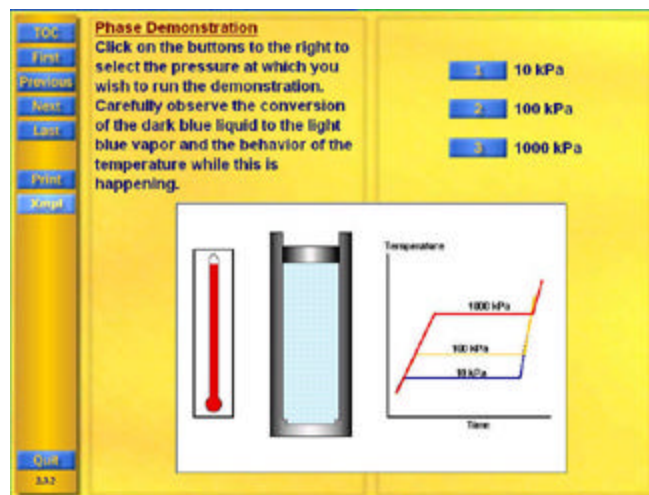


FIGURE 7
SUMMARY SCREEN FOR PHASE CONVERSION
EXPERIMENT

After conducting this experiment at the three possible pressures, the screen shown in Figure 7 appears. This screen summarizes the findings from the three experiments. The temperature histories clearly demonstrate that the pressure at which the phase conversion occurs changes the temperature at which it occurs. It also demonstrates that increasing the pressure increases the saturation temperature.

The final screen for this experiment is shown in Figure 8. The purpose of this screen is to begin the development of the concept of phase diagrams. The concept of a saturation line and of areas bounded by these lines representing the states at which different phases of the fluid occur are demonstrated in this screen. An audio voice-over that presents additional explanation of the concepts shown in this figure accompanies this screen.

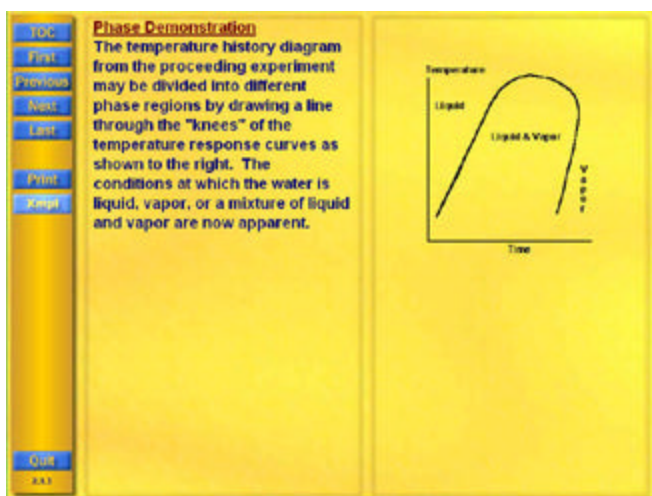


FIGURE 8
FINAL SCREEN OF PHASE CONVERSION
EXPERIMENT

After observing the temperature history of this experiment and learning what they can from this experiment, learners repeat the same experiments and obtain volume histories at the same three experiment pressures. Again, they observe that there are definite changes in the behavior of the system at the points where the liquid begins the conversion process and when all the liquid has been depleted. This behavior is different from that obtained in the temperature history and gives additional insight into the phase conversion process.

As before, this second set of experiments is summarized with a volume-time history showing the saturation lines and phase domains. The results of both experiments are then used to develop the pressure-specific volume state diagram by cross-plotting the results. Student comments indicate that they have a better appreciation of the pressure-specific volume state diagram and its application to state determination and analysis as a result of these virtual experiments.

COMPRESSION/EXPANSION WORK

This example is also more of a demonstration than a virtual experiment. Its purpose is to assist the learner in understanding the relationship between an integral, a process line, and physical reality. A demonstration involving an expanding piston-cylinder device as shown in Figure 9 was selected for this purpose. The screen of Figure 9 is near the end of an animation of an expanding gas volume, a state marker that follows the process line, and the area generated below the process by the running integral.

As in most of the previous examples, an audio voice-over containing additional explanation accompanies this screen. These voice-overs are included for the audio learners and to utilize one additional sensory input thereby improving the effectiveness of the learning process, Reisman and Carr [6]. Synchronized, always available audio clips are one of the advantages of CBI over printed material and lectures.

This animation is played over and over until the user clicks on the Next navigation button to move on to the next screen. Hence, the learner can observe this animation until they understand the knowledge it is conveying.

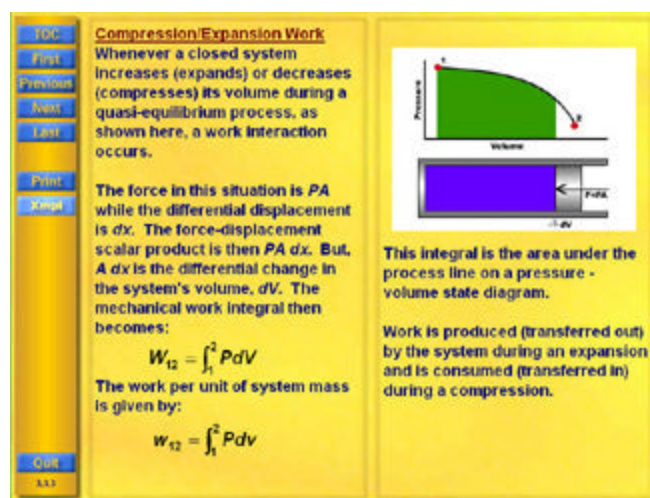


FIGURE 9
COMPRESSION/EXPANSION WORK EXPERIMENT

User control of the presentation of the material to be mastered is another learning benefit of CBI. One of the more frequently occurring student comments is that user control is a major advantage of CBI learning that places the focus on the learner rather than the instructor.

The last screen of this animation adds

$$w = \int P dV$$

to the green area of the state diagram. The fact that work is an integral and integrals are areas under quasi-equilibrium processes on state diagrams is presented three times, audio, textual, and graphical, during this screen. Repetition and

practice are classical techniques for improving the retention of knowledge and should be used wherever possible in CBI and other forms of instruction.

CONCLUSIONS

The preceding examples have demonstrated a variety of techniques for applying sound pedagogical techniques to the learning of thermodynamics with CBI. All of the examples have simulated experiments or demonstrations that can be done in the laboratory. But, by simulation with visual images and animation, many of the limitations of the laboratory are avoided. These limitations include:

- Expense of a laboratory
- Appropriate synchronization of experiment with other learning experiences
- Control over the results of the experiment
- Ineffective use of learner time
- Inability to readily and easily repeat the experiment

The virtual experiments presented here have addressed these shortcomings.

These virtual experiments have also incorporated several accepted learning practices. These include:

- Learner engagement
- Constructive feedback
- Coaching
- Exploration
- Discovery
- Iteration
- Physical world correlation

all of which are known to produce more effective learning and knowledge retention.

Readers who wish to review these, as well as other, experimental simulations and how they are used to teach the Introduction to Thermodynamics course may do so by obtaining the CD-ROM that is included with the Cengel and Boles textbook [10].

REFERENCES

- [1] Parmentier, Michael, "Featured Speech", *Simulation Interoperability Standards Organization, 2001 Spring Conference*, Orlando, FL.
- [2] Aedo, I., P. Diaz, C. Fernandez, G. Munoz Martin, and A. Berlanga, "Assessing the Utility of an Interactive Electronic Book for Learning the PASCAL Programming Language," *IEEE Trans. on Education*, **43**, 3, 403-413, August 2000.
- [3] Grimoni, J.A.B., L. Belico dos Reis, and R. Tori, "The Use of Multimedia in Engineering Education – An Experience," *ICEE Proceedings*, www.ineer.org, 1998.
- [4] Holzer, S.M., and R.H. Andruet, "Experiential Learning in Mechanics with Multimedia," *Int. J. Engn Ed.*, **16**, 5, 372-384, 2000.
- [5] Huson, A.R., and Kavi, K.M., "Interactive Teaching Practices in Small Class Sizes While Cutting into the High Cost of Education," *ICEE Proceedings*, www.ineer.org, 1999.
- [6] Reisman, S., and W.A. Carr, "Perspectives on Multimedia Systems in Education," *IBM Systems Journal*, **30**, 3, 280-295, 1991.
- [7] Renshaw, A.A., J.H. Reibel, C.A. Zukowski, K. Penn, R.O. McClintock, and M.B. Friedman, "An Assessment of On-Line Engineering Design Problem Presentation Strategies," *IEEE Trans. On Education*, **43**, 2, 83-89, May, 2000
- [8] Salzmann, C., D. Gillet, and P. Huguenin, "Introduction to Real-Time Control using LabView™ with an Application to Distance Learning," *Int. J. Engng Ed.*, **16**, 5, 372-384, 2000.
- [9] Bloom, B. S., "Taxonomy of Educational Objectives: The Classification of Educational Goals," by a Committee of College and University Examiners, New York, David McKay Co., Inc., 1956.
- [10] Cengel, Y. A. and Boles, M. A., "Thermodynamics: An Engineering Approach," Edition 4, McGraw-Hill, 2001.