# Application of Active Learning Techniques to Computer-Based Instruction of Introductory Thermodynamics[1]

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Abstract

Considerable research on the use of active learning techniques has revealed that both the depth of knowledge learned by the students and their retention of this knowledge is improved when these techniques are used. Based upon these findings, the authors have initiated the development of computer-based-instruction modules for the introductory thermodynamics course that incorporate active learning exercises. Active learning techniques incorporated into introductory thermodynamics modules include interactive exercises, immediate feedback, graphical modeling, physical world simulation, and exploration. This paper presents and demonstrates some of the active learning exercises developed to date specifically for this project. Assessment methods to measure the effect of active learning in virtual learning environments that are under development are also discussed.

## 1. Introduction

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 Nitendo Generation" whose first choice for learning is not static text and graphics, but rather interaction with rich multimedia and simulations. Consequently, the U.S. Department of Defense recently awarded major contracts

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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 and retain 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 it seems that 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 active learning exercises 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 own pace, receive appropriate feedback and coaching, and can review as often as necessary to master the material. This paper presents and discusses several such exercises that are integrated with a complete CBI system and textbook [10].

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. This course also contains many physical concepts that students are not familiar with most of which are easily observed with simple experiments. Therefore, this course is well suited to the use of active learning techniques integrated with the static elements of the course.

Assessment of active learning and other educational materials is commonly done by (a) comparing student performance (normally, final course or other grades) of sections or groups using the materials to sections that didn't use the materials, (b) measuring time-on-task, and (c) student satisfaction questionnaires. Although such measures give considerable insight into global performance, they don't measure things such as effectiveness of individual exercises, change in student knowledge base and change in their perception of knowledge gained, student attitudes towards course expectations, learning styles, and time requirements. But, these may be the more significant measures for instructional development purposes. Measurement of the impact of individual exercises on knowledge gained provides a gage that developers can use to discard or improve marginal exercises and retain successful exercises. Measuring the change in the knowledge state of a student is more meaningful for students who short-circuit or perform poorly in prerequisite courses, interrupt or modify course sequences, and who, in general, begin a course with varying knowledge bases. Another important change that should occur in lower-division courses such as Introduction to Thermodynamics is the transition from a low-risk, low-investment learner to a self-paced, life-long learner. Hence, it is important to measure this change and to tailor learning materials that contribute to the accomplishment of this goal. Assessment methods, currently under development for this project, that address these considerations are also described in this paper.

2. Active Learning Examples

**Interactive Questions –**The simplest active learning exercise to implement in a CBI module is the interactive question that usually takes the form of a multiple-choice or short answer question. Both of these formats are easily graded and immediate feedback based upon the user answer are readily programmed into the module. They also serve to interrupt passive learning which occurs as students read static text or listen to lectures. This interruption resets the student learning effectiveness to a higher level [9, 11] thereby improving the mastery and retention of the material.

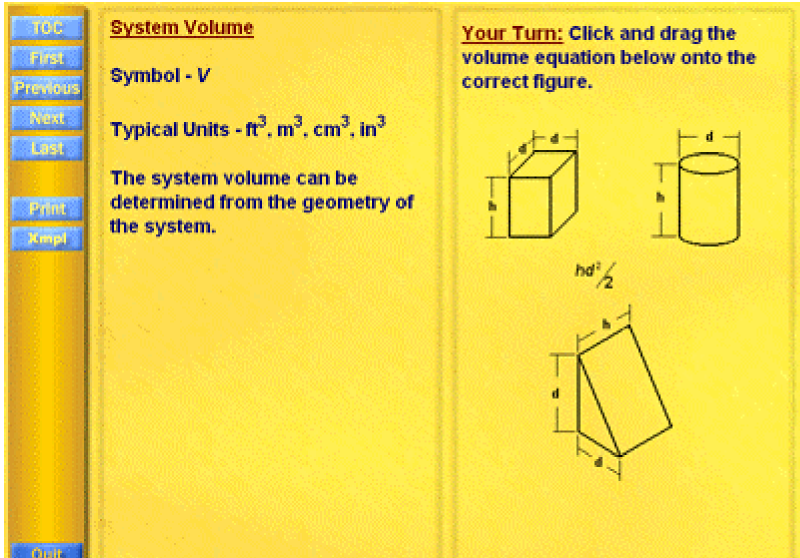


Fig. 1 - Multiple Choice Interaction Example

An example of this type of active exercise is shown in Figure 1. This particular exercise was taken from the one of the modules developed for this project. This exercise is basically a multiple-choice question which is to be answered by dragging the equation for the volume of an object onto the correct object which in this example is the triangular prism. This exercise appears following a brief lecture on extensive and intensive properties, and the system volume property. Its purpose is two-fold: to reinforce the concept of volume as an extensive property and to remind students that they are responsible for knowledge acquired in previous courses. If the student drags the equation onto the wrong figure, the equation returns to its original position as a visual means of coaching the student.

This particular example follows three screens of popup text synchronized with an audio voice over. Although the placing of exercises such as this is subject to the material being taught and the objectives of that material, their purpose is defeated if they are too infrequent. It is suggested that they not be more than 2-4 screens apart to keep students actively engaged with the material.

**Short Response Interactions –** Short response interactions are also known as short answer questions when the student enters text to answer the question. Engineering and the physical sciences often don't use text as a short response, but rather use digits, symbols, or equations for the short answer. These forms of input can be cumbersome in view of the limitations of the computer keyboard.

An alternative means of executing a short response input is presented in Figure 2. This exercise 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 or remove some weight until they have the proper amount of weight placed on the piston.

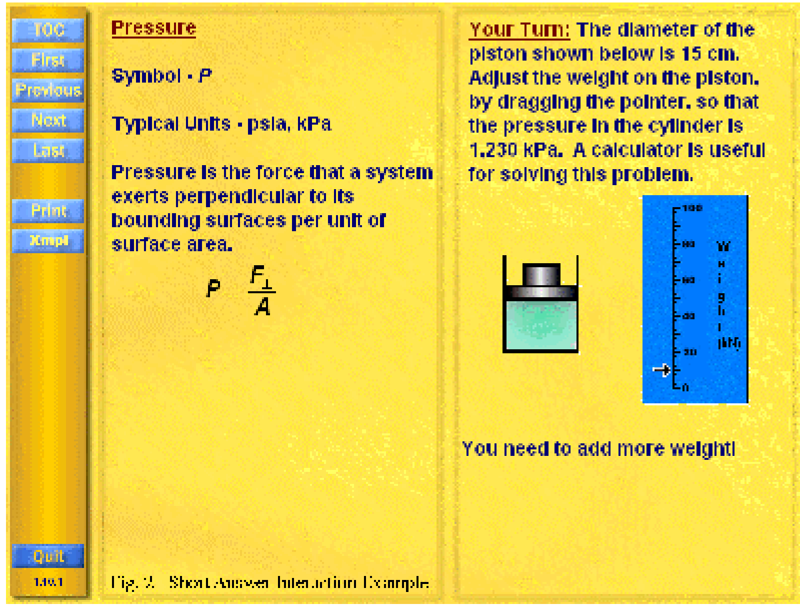

Fig. 2. Short Answer Interaction Example

This rather simple exercise 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.

**Coaching –** Student coaching interactions actively engage students in the learning process and allow them to discover knowledge and thereby retain that knowledge. Although coaching is most commonly used with other types of exercises that provide feedback when the student completes the exercise, it can be accomplished in other ways.

An example of an alternate application of coaching in this project is shown in Figure 3. This application encourages the student to explore the various terms of the equation on the right-hand-side of the screen by dragging the cursor over the terms. Once the cursor is over a specific equation term, a coaching message, like that shown in Figure 3, appears. The first law of thermodynamics has been thoroughly discussed using pop up text synchronized with voice overs in the screens proceeding this exercise. These coaching messages then serve to reinforce the previous presentations.

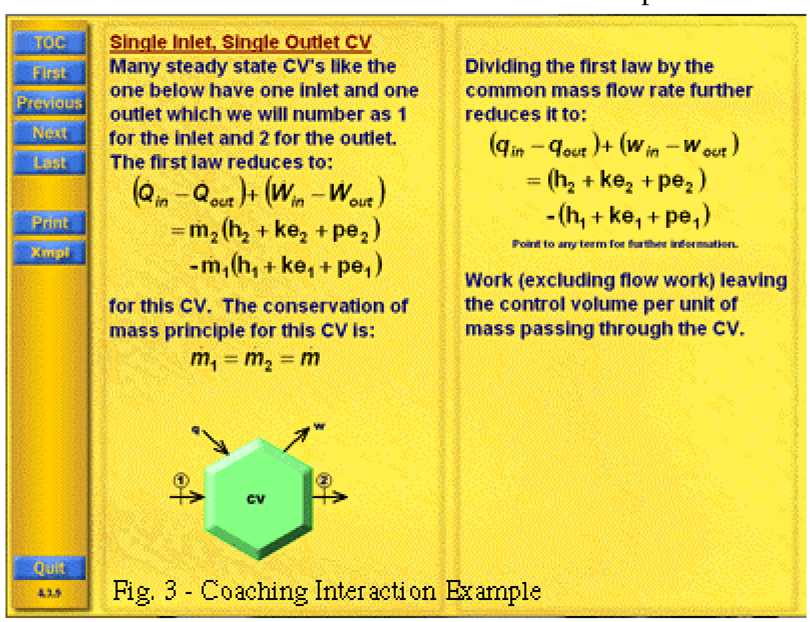

Fig. 3 - Coaching Interaction Example

In addition to repeating the information and reinforcing it, these coaching messages serve to engage the visual learner rather than the audio learner who was engaged during the proceeding screens. One of the principle benefits of CBI is that it can accommodate many different learning styles.  Instructional developers should always take advantage of this benefit and use it to actively engage the learners.

**Experimental Simulations –** Another method of actively engaging students with the information is to have them perform simulations of physical experiments.  The simulation shown in Figure 4 demonstrates liquid-vapor phase conversion as a substance undergoes a constant pressure heating process.  During this conversion experiment, temperature-time and volume-time data are plotted. The final screen for the volume-time simulation is presented in Figure 4.

The experiment is performed in the piston-cylinder device shown in Figure 4.  As heat is transferred from the flames to the water in the piston-cylinder device students can observe the relative amount of liquid and vapor, the total volume of the liquid-vapor mixture, the temperature of this mixture, and a plot recording the system volume as time passes.  This plot is synchronized with the location of the piston.  Students run this experiment at three different pressures by clicking on the appropriate buttons.  The final results of this experiment are shown in the data plot of Figure 4.

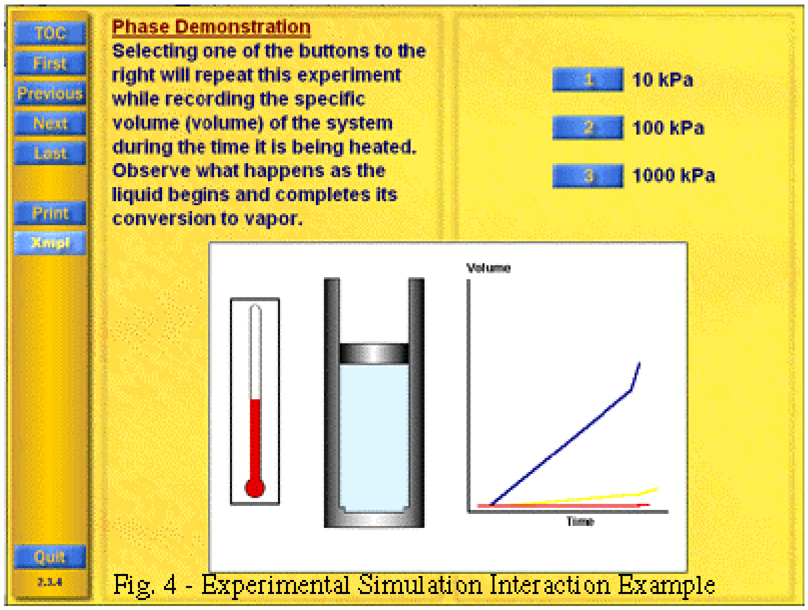

Fig. 4 - Experimental Simulation Interaction Example

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.

This simulation may actually be preferred to a similar physical experiment.  In the laboratory, it is difficult to physically create equilibrium, heat transfer and transient effects make it difficult to observe the points of volume-time slope discontinuity, 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.

The screen immediately following that of Figure 4 is shown in Figure 5.  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 saturation 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.

The volume-time behavior of this experiment is the second in the set of experiments performed by the student. Prior to performing this aspect of the experiment, students performed a similar temperature-time experiment. 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.

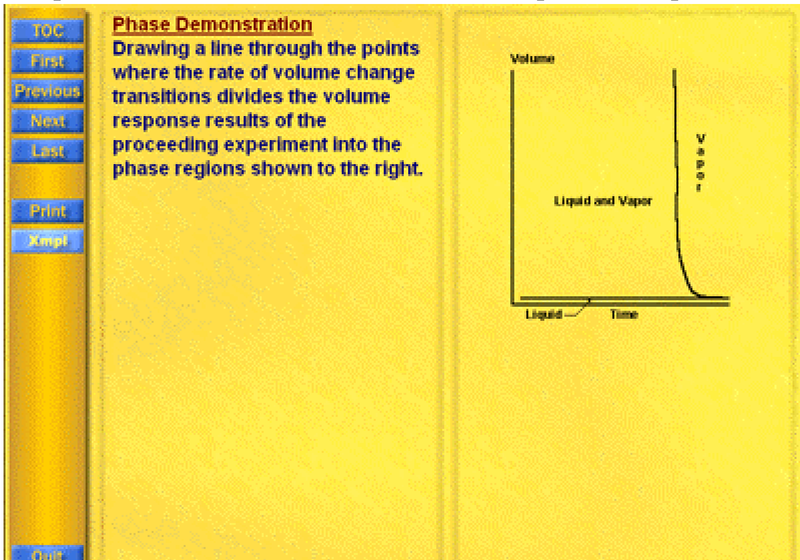


Fig. 5 - Experimental Simulation Conclusion Screen

3. Design of Assessment Processes

**Attitudinal Assessment –** As indicated in the introduction, part of the project is to measure the change in a student's attitude towards the course, self-learning expectations, preparedness for CBI, and utilization of CBI materials. To this end, a questionnaire was designed to be administered at the start of the course and at the end of the course. The questions are the same both times. But, the first time the questions are phrased in terms of what the student expects to do or experience while students are asked to describe what they actually did or experienced the second time the questionnaire is administered.

The first portion of this questionnaire is dedicated to basic student information including gender, ethnicity, major, total credits earned and number earned in engineering, hours currently enrolled in, and expected course grade. Most of this data is collected to gage the student's maturity as a college student and engineering student, as well as their current course load. Perhaps the most significant question is the one about expected course grade. This is intended to measure the change in the student's perception of the course over the semester. It is expected that this should correlate well with student maturity and course load.

This questionnaire was administered the first time during the Fall 2001 semester. Analysis and interpretation of the data are presently underway and will be reported as it becomes available [12].

**Knowledge Assessment -** The second portion of the assessment is designed to assess both the knowledge gain on a microscopic and cumulative level. A set of homework problems has been put online and daily homework assignments are made against this set. Each student gets one of three possible, randomly selected questions sets whose questions contain randomly generated parameters in their statements. Thus, it is a rare coincidence when two students will be given exactly the same question. Each question set is written to meet the testing objectives of that set. These objectives are available from the first author. Then, although question sets are selected at random, all sets in a group test over the same objectives. Also, each question set is keyed to certain material in the textbook, lecture, and CBI materials such that performance on a given set can be used to measure the effectiveness of the various materials.

Each question set consists of five questions. At the beginning of the course, these are five different questions. But, as the course progresses and the students become more comfortable with the material the five questions or some portion thereof cover some of the intermediate steps of a more comprehensive analysis. For example, a question set for the simple Rankine cycle, which occurs late in the course, may begin with a question about the entropy at turbine inlet and end with a calculation of the cycle efficiency.

Student performance on each question set is measured by time-on-task, grade on each question, and grade for the question set. This information is then used to make adjustments and refinements to the course materials at the microscopic level. After adjustments are made, this data is used to measure the impact of the adjustment upon knowledge gain. Anyone wishing to try out these home work sets can do so by going to the URL *www7.tltc.ttu.edu/thermosite* and entering the system as a TTU student with the username *guest* and password *guest*. Contact the first author if you would like your students to participate in this phase of the project.

A fourteen question, multiple-choice, 50-minute test has been designed to measure the cumulative knowledge of each student. This examination is administered near the end of the course as a not-for-credit examination in an attempt to measure a student's knowledge base without significant examination preparation. We are attempting to measure the knowledge that will likely be retained rather than knowledge mastered for the examination and then forgotten. Incentives such as dropping homework scores and suggesting student use this to prepare for the final examination are used to get student to take the examination. We plan to use the same examination instrument throughout the duration of the project to get a consistent measure of the cumulative knowledge gain. This instrument is currently being put online.

**Usage Assessment –** Much of the CBI content has been programmed and is being made available to students in CD-ROM format. We are presently reworking this content to place usage measures within the content. These usage measures will measure several things: time spent on a screen, number of times a given screen is visited, and student performance on interactive exercises like those described in Section 1 of this paper. The goal of this extensive data collection project is to determine which screens are in need of refinement and improvement. These are still being programmed into the content at this time.

## 4. Conclusions

One of the biggest impediments to using CBI is the limited ways in which students can interact with the materials. CBI designers must carefully consider the goals of each step of a learning program and find ways to accomplish these goals within the confines of possible CBI interactions.

This paper has illustrated the application of active learning techniques to CBI learning modules for a typical engineering Introduction to Thermodynamics course. The techniques presented in this paper are but a small set of many possibilities and the final set of Introduction to Thermodynamics modules contains several others. The set presented in this paper were selected specifically to demonstrate alternatives ways of asking multiple-choice and short answer questions since many teachers feel that these formats are too restrictive for science and engineering purposes.

The program for assessing the this project has also been described. To date, the program has one full semester available to it for assessment [12]. Hence we have just begin to gather the data and have not had the opportunity to fully correlate and analyze the results. Our findings will be reported in the future.

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