Helping Students Become Proficient at Solving Fundamental Engineering Problems through Practice – The Homework Laboratory

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Abstract – *The Homework Laboratory*® (The HWL) is a CD-based educational tool for use in fundamental science and engineering courses. Capable of being used with virtually any quantitative course of study, it is intended to help students learn the course material in a more effective manner and to make the administration and presentation of the course easier for the instructor. The National Science Foundation sponsored the testing of the software (using control and experimental groups of students) to assess its effectiveness at improving student understanding. The test program was conducted over a three-year period in engineering mechanics classes at The University of Texas at Austin (UT) and Tennessee Technological University (TTU). Also, in order to assess the modularity of the programming (that is the ease with which new courses may be added) the software was modified and implemented in a high school statistics course. This paper describes the function and navigation of The HWL and the administration and use of the software at TTU, UT, and Monterey High School.

Keywords: Learning software, Education, Engineering mechanics

INTRODUCTION

In the course of learning something new, nothing is more important than practice. The traditional method of teachers assigning homework supports this idea: students need to practice in order to learn. In many courses, however, students bypass the learning that is built into the practice. By simply working some introductory problems, or getting answers from other students or class files, many students fulfill course requirements for homework while learning little. This is often reflected in high homework scores but low test scores.

Students, however, are not the only ones suffering under the traditional homework model. The time associated with grading the large number of problems in heavily populated fundamental engineering courses is exorbitant for the instructor. A typical engineering mechanics course, for example, might require 100 problems for each of the 50 to 150 students (5000 to 15,000 problems that must be graded each semester).

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Careful delivery of internet-, network-, or CD-based interactive instructional tools has the potential to remedy both problems. Computer-based instruction involving significant practice and often incorporating commercial engineering software has been proven to be effective at enhancing student comprehension and retention [4, 6]. Clearly, budgetary constraints as well as improvements in multimedia technology are pushing universities toward more reliance on this approach [7].

The Homework Laboratory® (HWL) is a multimedia software package designed to augment student understanding and exam-readiness while also saving the instructor a considerable amount of time in terms of grading and assisting students. It is administered via CD, DVD, or over a campus network, using Windows-based PCs.

The HWL is designed in a modular fashion so that it can be easily linked with a particular textbook. The problems in the text are programmed into the software and the input variables are randomized. The specifics for each problem are stored in an independent database. This modular design simplifies the modification of the software to include new subject areas. The **Student Version** of the HWL performs the following functions:

- randomizes the variables for a student's homework so that each problem is different for every student;
- instructs the student when calculation errors are made;
- provides students with randomized and timed practice tests to help them gauge their progress and prepare for class exams;
- scores each homework problem and tracks student grades on homework, practice problems, and practice tests; and
- provides virtual classroom lectures that are searchable by keyword or chapter.

The **Instructor Version** allows the instructor to:

- assign problems for a semester and easily distribute the assignment electronically (e.g., e-mail or internet);
- print a syllabus of assignments;
- view individual student grades or grades for an entire class;
- import grades into a spreadsheet;
- determine the correct answer(s) for any problem with any set of variables; and
- monitor the amount of time students have spent on the various sections of the HWL.

The National Science Foundation (NSF) sponsored the testing of the software (using control and experimental groups of students) to assess its effectiveness at improving student understanding. The test program was conducted over a three-year period in engineering mechanics classes at The University of Texas at Austin (UT) and Tennessee Technological University (TTU). Also, in order to assess the modularity of the programming (that is the ease with which new courses may be added) the software was modified and implemented in a high school statistics course. Though the HWL is capable of being used with virtually any quantitative course of study, engineering mechanics was chosen for this research along with the textbook *Engineering Mechanics – Statics* [2]. This paper describes the function and navigation of The HWL and the administration and use of the software at TTU, UT, and Monterey High School.

STUDENT VERSION

The HWL Student Version is designed to have a simplistic navigational style with the four main functions shown in Figure 1. Supplementary functions (generally accessed by a right click) include viewing grades, printing homework problems, changing the student password, and creating back-up copies of student work. However, before students may begin any of the main practice functions, a mechanism for recording their work must be initiated. With The HWL, student work is written to a file called a student data file (SDF). It is created by the instructor using the instructor version and distributed (via e-mail, web page, etc.) to all students in the class. The SDF is encrypted (so that it can be viewed or edited only by using The HWL) and when distributed by the instructor, is in a generic form containing only problem assignments. Ultimately, however, it is modified by the software as the student uses it so that it contains their username, password, assigned homework problems, homework and practice test results, and how much time they have spent in each section of The HWL.

Therefore, before a student can do anything in The HWL, they will be prompted to select a valid SDF for use. If the file has never been used before (i.e., if it is the generic class SDF created by the instructor), they will be prompted to give their name and a password. In the future, each time they use The HWL, they will supply this file when prompted, and input their password. After a valid SDF has been selected and the password either set or verified, the student may then begin the practice process by using one of the four main functions.

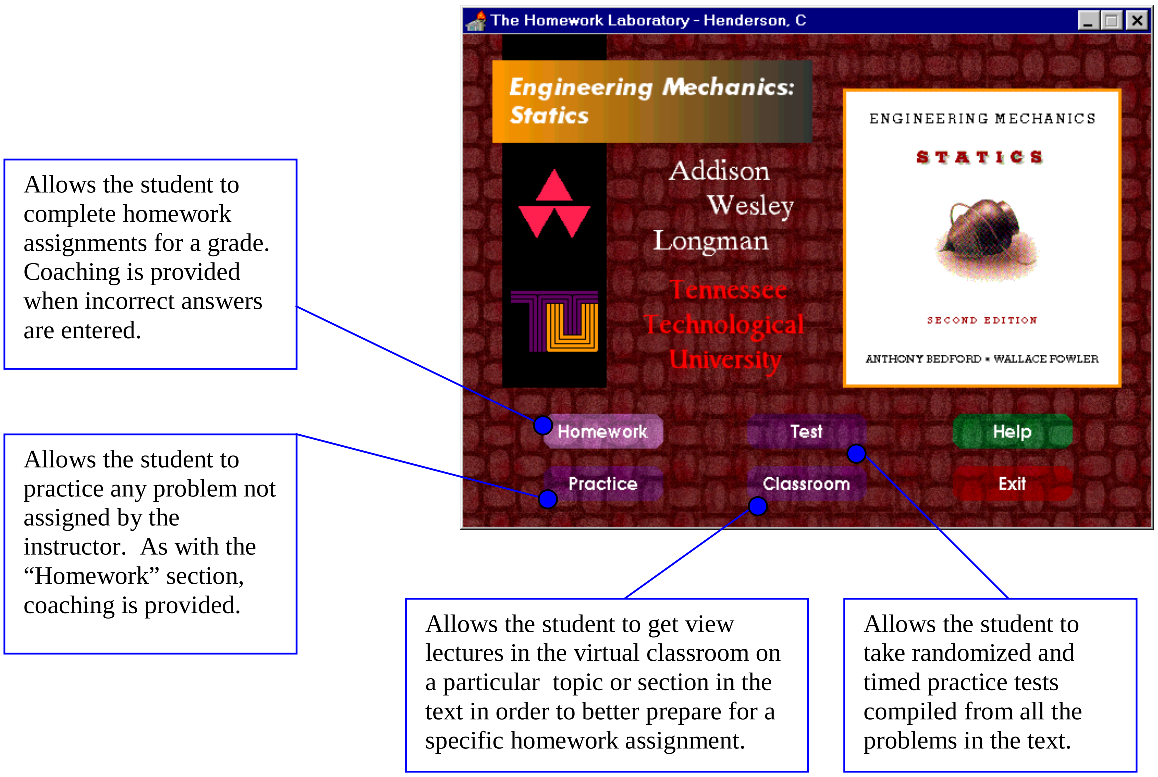


Figure 1. Student Version Main Screen

Homework and Practice

The *Homework* section of The HWL contains only those problems assigned by the instructor (using the instructor version), while all other problems not assigned are available to the student under the *Practice* section. Working a problem is the same in each section, and grading and coaching are identical as well. The two sections are separated merely for bookkeeping purposes – that is to distinguish between problems worked for practice (or extra credit from the instructor) and those worked for a grade. Therefore, the following description is pertinent to working a problem in either section.

The first step is to select a chapter and the homework problem to complete as shown in Figure 2, left.   Audio and video help has been implemented for navigational assistance using the HWL. [However, this feature has been unnecessary for most students.] The graphics on each of the hexagonal chapter selections match the textbook graphic for that chapter. Likewise, the graphics used throughout the HWL have been chosen to fully integrate the software with whatever text is being used. The intent of both the graphical and navigation design was to help the student feel as though The HWL is a seamless extension of the textbook – not an additional element that must be mastered. After the student selects the desired chapter, they will be presented with a screen that will list all of the sections in that chapter as shown in Figure 2, right. When the mouse is moved over a section title, the problems (both the number and the thumbnail of the problem graphic) for that section appear in the space to the right.

Moving the mouse over to the list of problems, the student then clicks on the problem they wish to work. This will load in the selected problem in one of two ways:

1. With new random variables if they are working a Practice problem or a Homework problem they have not entered before, or

2. With the same random variables they had last time if they are working a homework problem that they started earlier but did not complete with a correct answer.

A typical engineering mechanics problem is shown in Figure 3, left. This problem consists of three randomized input variables: the weight of the upper block, the weight of the lower block, and the angle of the incline (up to six variables may be given for each problem). The problem requires that the force necessary to hold the system in equilibrium be calculated (up to six answers may be required for each problem). After working the problem, students enter their answers into the appropriate text boxes and click the *Submit* button. If their answers are correct (within 0.5%) they are informed of their score and it is recorded to their SDF. However, if any of their answers are incorrect, a deduction is administered, and assistance in finding the correct value is provided as shown in Figure 3, right. All deductions are also recorded to the SDF.

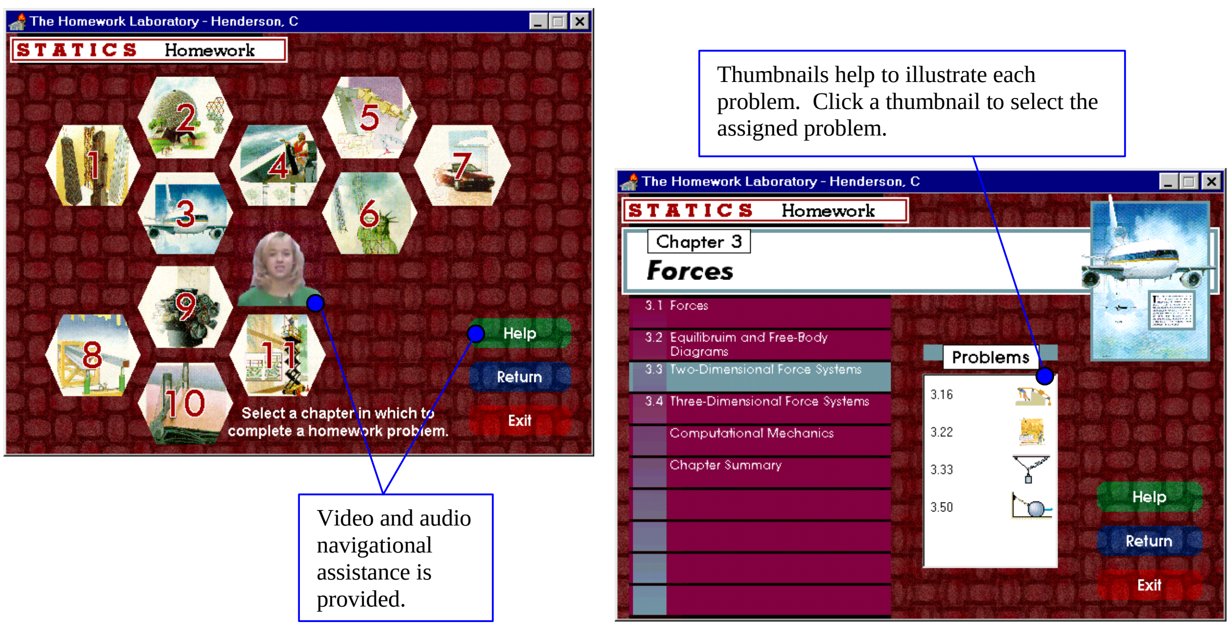


Figure 2. Selection of Chapter and Problem

It should be noted that the intent is not for the student to work the problem while sitting at the computer, but rather to print his/her version of the assignment (using the print button) and work it completely on paper – checking all answers thoroughly and drawing the requisite figures and free body diagrams. Only then should the student input the calculated solutions. The student may exit the program and return to the problem at any time. The student's solution (including all deductions and intermediate values) is stored in an encrypted format that prevents the altering of grades, deductions, or any portion of the problem.

Each time a student answers a homework problem incorrectly they are penalized two points out of a possible ten points. If they miss a problem five times, they can start over (as if they never worked the problem) with a new set of random variables. Therefore, it is possible for students to achieve a perfect score on each problem, but this may require working the problem several times with new randomized variables. This concept has two direct benefits: (1) it encourages practice by offering the incentive of perfect homework scores; and (2) it encourages methodical and accurate work (i.e., clear drawings, checking calculations, etc.) in order to avoid incorrect answers. These benefits are extremely important for success, both in future classes as well as for licensure testing (e.g., FE and PE exams) where only correct answers receive credit.

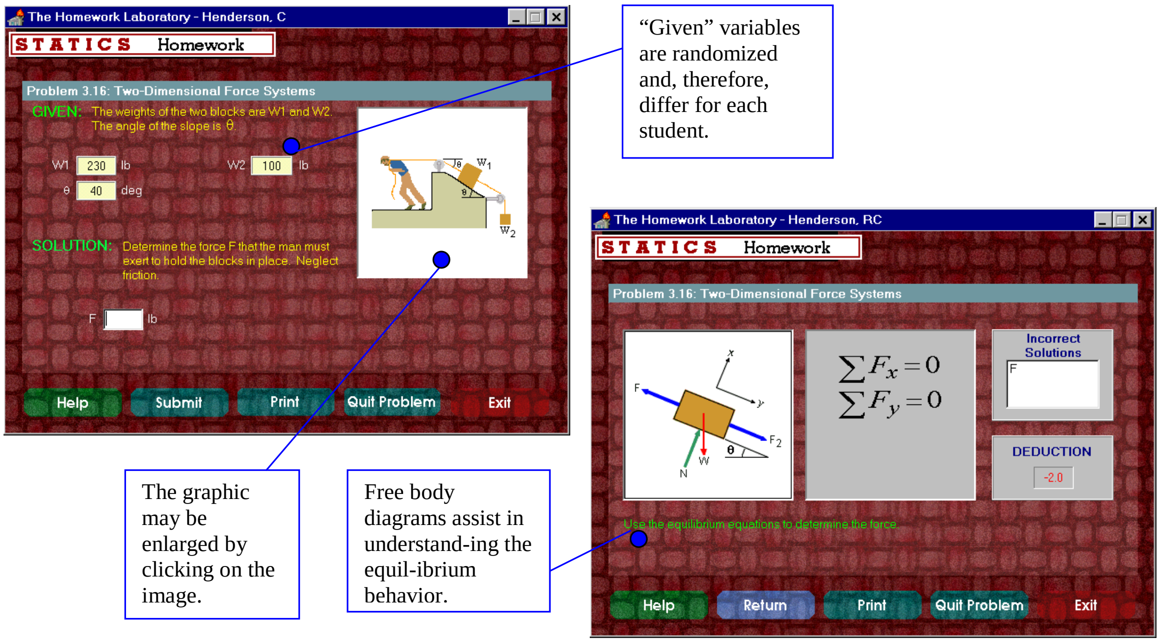


Figure 3. Homework Problem and Coaching Screen

Practice Tests

Another one of the primary tools that The HWL offers is the ability to take timed practice tests comprised of problems randomly selected from user-defined sections of the text. After choosing the sections over which they wish to be tested, the student then specifies a time limit for the practice test.   The HWL selects a set of problems that a reasonably prepared student may be expected to finish in the allotted time. For example the student might choose to be tested over Chapter 3 for one hour and 40 minutes. In Figure 4, six Chapter 3 problems were randomly selected. The student clicks an image to view detailed information about the problem which displays a problem screen very similar to Figure 3, left. The student is encouraged to print all problems on the test (using the print button) and work through them methodically as he/she would on an actual in-class test. When answers have been calculated, checked, and input for each of the six problems, the student clicks the *submit* button. The HWL then grades the student's answers and provides a breakdown of his/her score on each problem as shown in Figure 4, right.

Classroom

In The HWL's virtual classroom (see Figure 5), the student receives assistance with general concepts in preparation for specific homework assignments. For example, while working a practice or homework problem in Chapter 6, the student may find that he/she needs background help on "centers of mass". This topic may be located by either a chapter or index search (keyed to the index of the textbook). The HWL then provides a tutorial on the specified topic in a step by step manner. The classroom section uses Microsoft's PowerPoint viewer. The student can proceed at their desired pace using standard navigational controls or print out the lecture for note taking.

View Grades

The ability to assess progress is an important element for student success in any course. The HWL provides a mechanism for students to monitor their grades on homework, practice problems, or practice tests. To do this, the student may right-click on any main screen within the HWL. This action produces a summary of all work up to the current date – either in progress or completed. The details of individual work are listed first, followed by the "statistics" section which provides the total number completed in each category (i.e., homework problems, practice problems, and tests) and the averages of each of the three categories. Dates of completion are recorded for the student in a fashion similar to the instructor version.

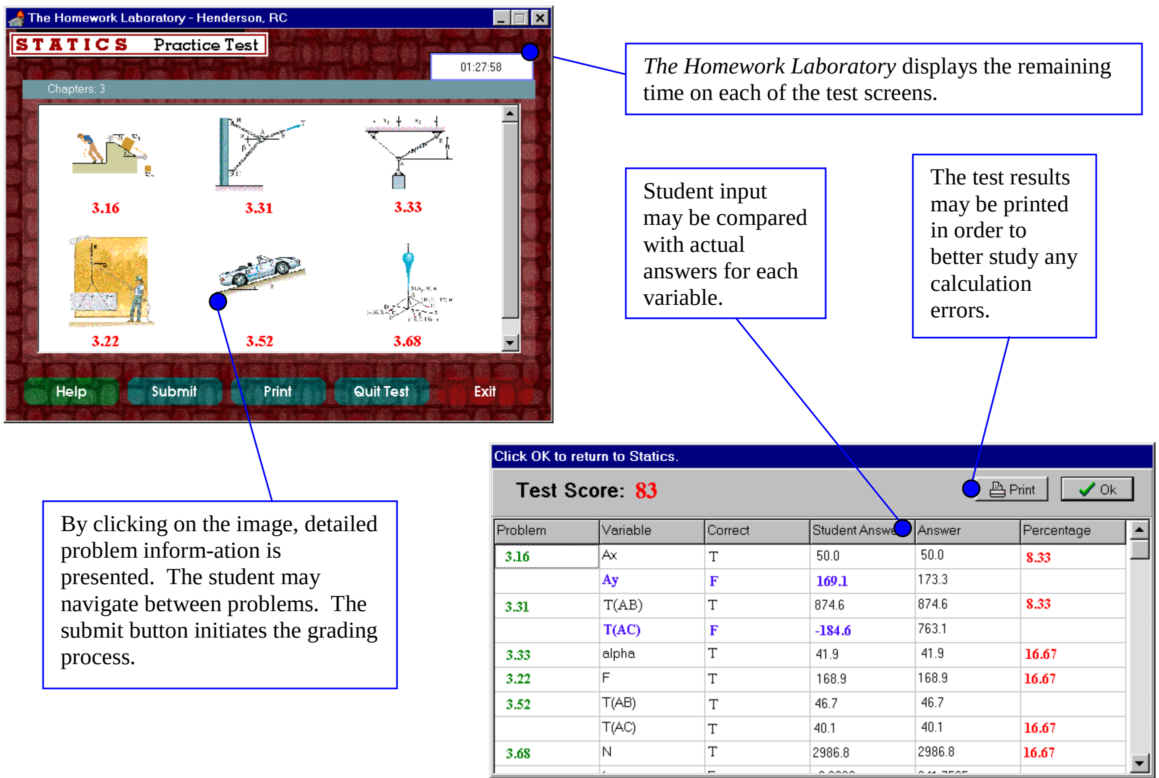


Figure 4. Test Layout and Scoring Summary

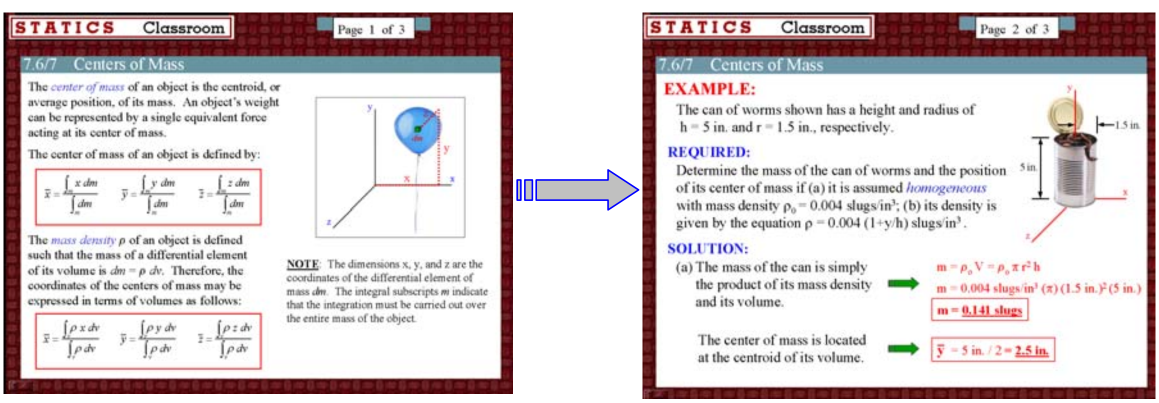


Figure 5. Virtual Classroom

INSTRUCTOR VERSION

The HWL Instructor Version has been designed to provide flexibility for the instructor in the areas of problem assignment, tracking student progress, and assisting the student with a specific problem. This is accomplished via the following four menu options:

Assigning Problems: The first step in using The HWL is to create a generic SDF for the class. The instructor may assign any of the problems in the textbook (i.e., individual problems, as well as whole sections and chapters) using a simple click and drag procedure. The generic SDF created for a class can then be distributed via disk, e-mail, or internet download from a class web page as discussed in the STUDENT VERSION section. All problems not selected by the instructor are placed in the practice section of the HWL.

View Student Record: The HWL also provides instructors with two ways to view the results of the students' work. First, the instructor can see all of the student's homework scores, practice test scores, score averages, how much time the student spent in each section of The HWL, and the student's password (if necessary, an instructor can reset a student's password from this screen as well). The second way to view student results is to use the Multi-open command and view a group of student files at once. Class grades may also be copied to the clipboard, imported into Excel, or saved in CSV or text format as shown in Figure 6. As indicated, the grade is shown if they have completed a given problem, a dash is shown if they have not started it, and it is labeled 'IP' if it has been started but they have yet to answer it correctly (in progress).

Normal Mode: This section allows the instructor to start the Student Version of The HWL using a student's SDF without supplying the password. This is useful if an instructor needs to check the random variables being set on a particular problem for a particular student.

Answer Mode: One of the basic principles behind The HWL is that when students start a problem for the first time, they receive a set of randomly generated variables within appropriately set bounds for the problem. That way, each student is effectively working a "different" problem. Randomization of variables, however, makes it difficult for the instructor to assist students without first working each problem. The Answer Mode assists the instructor by calculating answers to any set of input variables.

Course:	Engineering Mechanics
Section:	23204
Date:	February 22, 2000

Note: "I.P." = In Progress
"—" = Not Attempted

Course and date information is provided to better track student work.

Name	1~24	2~8	2~29	2~30	2~48	2~72	2~82	2~95	2~112	2~118	2~130	Avg
Adamson, JC	10	6	8	10	10	10	9	8	10	6	10	8.8
Adcock, RM	10	10	10	10	10	10	10	10	10	10	10	10.0
Boratelli, AA	10	10	10	4	10	10	10	10	7	10	10	9.2
Clough, CR	10	10	10	10	10	10	10	10	10	8	10	9.8
Evans, OB	10	10	10	8	10	10	0	10	10	10	10	8.9
Henderson, RC	10	10	10	10	10	10	10	10	10	10	10	11.0
Henricks, CB	10	10	10	10	10	10	10	10	10	10	10	10.0
Isaac, FA	10	10	10	10	10	10	10	10	10	10	10	10.0
Jacobs, WA	10	10	10	10	10	10	10	10	10	10	10	10.0
Link, PR	10	10	10	10	10	10	10	10	10	10	10	10.0
Matthews, RL	---	---	---	---	---	I.P.	I.P.	I.P.	---	---	---	0.0
Mullins, AS	10	10	8	10	10	10	10	10	---	---	---	7.1

Student names are alphabetized and grades are averaged.

Figure 6. Display of Grades for a Class

IMPLEMENTATION AND TESTING

Evaluation of a curriculum innovation is essential to providing information for decisions about the program. This is particularly true when examining the effects of a new technology on a learning group. Ayers and Collins [1] developed and implemented an evaluation model for curricula innovation that was applied successfully to a program for the training of undergraduate engineering students in real-time digital systems. This research on the effectiveness of The HWL used a modified version of this cyclic assessment model. The main emphasis of the approach was to:

1. implement The HWL at TTU and UT Austin;
2. periodically evaluate the effectiveness of the software at improving student learning;
3. periodically evaluate the effectiveness of the software at meeting the needs of the instructor;
4. modify the software and reevaluate;
5. complete a final quantitative evaluation; and
6. modify the software for a new text and implement it in a high school setting.

The HWL was used in engineering mechanics classes at TTU and UT Austin over a three-year period. The two schools differ in many ways (classroom size and demographics, computer network configuration, homework policy and scoring, student approaches to subject preparation, etc.), thus, providing an excellent testing ground for the software.

The method for evaluating the software consisted of quantitatively comparing the test scores for students who used The HWL in engineering mechanics to those who used the traditional approach to homework. This was accomplished by having the instructor at both schools teach an experimental class (i.e., those using the software) and a control class (those using the traditional approach). Additionally, a questionnaire was given each semester to the students in the experimental group requesting feedback on positive and negative aspects of the software, recommendations for improvement, and how The HWL compares to the traditional approach. Frequent assessment interviews with the instructors were also conducted. Based on each semester's evaluation findings, the software was modified, re-implemented, and reevaluated. TTU had 187 students participate over a period of four semesters; while UT had 405 students participate over three semesters.

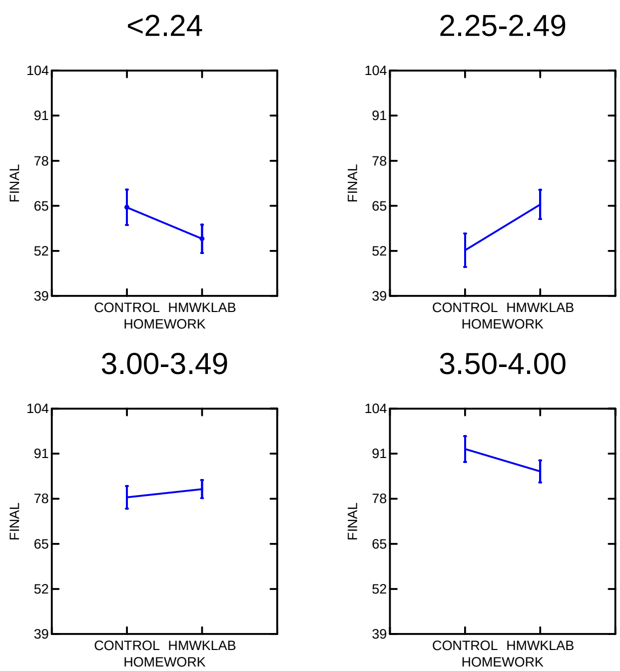
A statistical evaluation of the study participants at TTU sought to answer the following questions:

1. Were the treatment groups originally equivalent in ability (entering GPA) before any treatment was administered?
2. Is there a difference in achievement (final examination scores and course grades) between the experimental group and the control group overall (i.e., regardless of GPA level)?
3. Is the difference in achievement between the experimental group vs. control group the same for students in different entering GPA groups or levels?

Both entering GPAs and scores on pretests were used to evaluate question number 1. Both indicated equivalency. The difference in initial GPA's between the experimental and control groups had a probability of 0.59 of occurring by chance. Therefore, the difference is not statistically significant. In fact, the GPA means for the experimental and control groups were very similar. Clearly, the experimental and control groups were equivalent at the beginning of the study.

A two-factor (2 x 5) analysis of variance for final exam scores in the engineering mechanics classes was completed [Note: Final exams for all 187 TTU students were identical and comprehensive]. The results of the analysis for the course grades were almost identical to the results for final examination scores. The two factors were homework treatment (experimental or control) and entering ability from low to high. A statistical comparison of the groups indicated that the experimental group (115 students) did better on the final exam than the control group (72 students), but not significantly (P = 0.543), thus the answer to question number two for the study.

Interestingly, Figure 7 compares the final exam performance of the experimental group to the control group students by each ability (entering GPA) group. This plotted interaction is significant and shows that for those 34% of students whose GPA is either below 2.24 or above 3.50, the conventional method of instruction produces better final examination scores. For those 66% of students whose GPA is between 2.25 and 3.49 (the three middle GPA groups) the HWL produces better final exam scores. In other words, Figure 7 shows that the exam scores are significantly better for the 2.25-3.49 group when they receive the HWL treatment. Also important is the fact that over 70% of the students who used The HWL indicated that they would prefer it to traditional approaches to homework. This number improved to over 80% during its final semester of use at TTU.



GPA Group	No. of Students
<2.24	23
2.25-2.49	23
2.50-2.99	45
3.00-3.49	56
3.50-4.00	40

Figure 7. Least Squares Evaluation – GPA Treatment vs. Final for GPA Levels

SOFTWARE MODULARITY

For any software package developed in today's market, the ability to efficiently upgrade and/or modify it for a specific system within its scope is necessary. The HWL was designed to ensure that the end product could be easily and efficiently modified to work with almost any quantitative subject material. Significant effort at the start of the project was devoted to determining the most appropriate programming language for the development of the project. Ultimately, Borland's Delphi (visual Pascal) [3] was selected as a mix between low-level code control and high-level rapid application development tools.

The final stage in the study was the retooling of the software for use with a different course in a high school setting. The intent of this phase was: (1) to investigate the modularity of the software design (that is the ease with which new courses may be implemented) and (2) to qualitatively determine the effects of the software on a different set of learners.

Figure 8 shows, in a general way, the interaction of the different modules of The HWL. Adhering to the software engineering principle of minimal interaction, the interfaces between these modules are clearly defined and as reduced as possible. Because of this, adding or changing problems in no way affects the overall operation of The HWL, and changes made within the control bounds of the Navigation and Operation code module do not affect the working of the problems. As long as the interface remains unchanged, the integration of the modules remains stable.

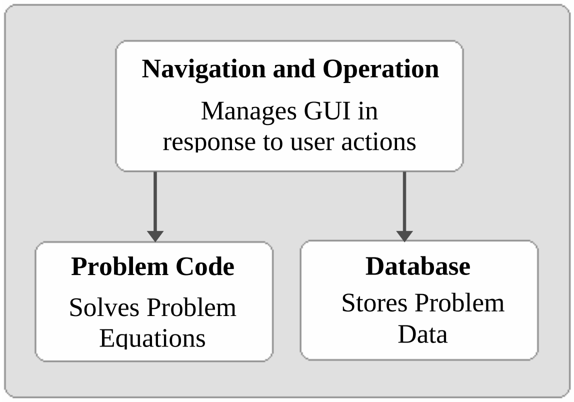


Figure 8. Simplified Modular Layout

This means that changing the subject material covered by The HWL does not involve changing any of the navigation code, and only minor changes to the operation code. Each chapter covered has its own unit with code for its problems only. Each problem is a procedure that is called by the operation code. Thus, when problems are added, the only change that takes place in the operation code is to add the new problem name to the list.

CONCLUSIONS

NSF's 1994 conference entitled "Project Impact: Disseminating Innovation in Undergraduate Education" outlined several important phases toward completing a particular education reform. These include: (1) pilot study, (2) revision and testing, (3) working with a publisher and (4) focusing on a national level [5]. This study has attempted to follow this course of action. The results of the study were positive in many ways and may be categorized into two primary areas: (1) lessons learned regarding the development of pedagogical software and (2) lessons learned regarding the implementation of pedagogical software on learning groups.

Regarding the first issue of implementing pedagogical software, The HWL was found to improve student test scores by a few percentage points – though this finding is not statistically significant. However, when the experimental student population was grouped as a function of GPA, mid-level students improved the most (statistically significant improvement) whereas higher and lower GPA students were helped the least. In general, over 70% of the students who used The HWL indicated that they would prefer it to traditional approaches to homework.

Regarding the second issue of software development, The HWL project demonstrated the effectiveness of a modular database approach to educational software development involving the presentation of fundamental science or engineering concepts. Though an integrated code approach may have reduced the size of the code package [The HWL is a large program – well over 50,000 lines of code], the swapping of course material would have been significantly more difficult.

Furthermore, for this type of application, a versatile and robust development application must be selected. Many development applications are primarily graphical presenters, with limited calculation power. Others are efficient solvers, but formulation of the graphical user interface (GUI) is laborious. A balance in these areas is preferable. Borland's Delphi 3.0 worked well for this application.

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