ThermoNet:: A Web-Based Learning Resource for Engineering Thermodynamics

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Abstract

ThermoNet is a comprehensive web site being developed under NSF sponsorship to provide internet-based learning resources for students in engineering thermodynamics. The site includes a series of tutorials covering the topics typical of introductory engineering thermo courses, interactive example problems, thermodynamic property tables with an on-line calculator, historical and biographical notes on the evolution of thermodynamics, a rich archive of graphics, animations and movies illustrating thermodynamic principles and applications, and links to other sites of thermodynamic interest. Conceptual and detailed design of *ThermoNet*, implementation of a server-based data acquisition system to collect data on student use patterns, and evaluation of student learning styles and reactions to *ThermoNet* are discusssed.

Introduction

Engineering thermodynamics, typically introduced at the sophomore level in mechanical, aerospace and chemical engineering curricula, is often anticipated with a degree of dread by students, who perceive the subject as dry and abstract. The material is not, by nature, as graphic as many other engineering topics (e.g., mechanics), so many students have problems visualizing thermodynamic phenomena and processes. Laboratories are virtually nonexistent due to the expense of equipment and the slow process of gathering meaningful data. While many excellent textbooks have been developed, conventional printed media are limited in their ability to elucidate complex concepts both by their inherent static and passive nature, and by the high cost of graphics.

Educators generally agree that hypermedia technology can be effective in teaching and learning[1]; the ability to represent information in diverse forms can accommodate the needs of various types of learners[2], although not all media are equally effective with all learners. For teaching of engineering subject matter, hypermedia systems offer a new oppportunity to overcome some of the limitations of conventional media. Graphics-rich content, including animations, sound and video files, can be delivered inexpensively via the World Wide Web or CD-ROM, and interactivity can easily be incorporated via Javascripts and Java applets to draw the learner into the active learning process.

In 1996, a grant was received from the National Science Foundation[3] to support the development of *ThermoNet*, a web-based learning resource for instruction in engineering thermodynamics. This grant was the successor to a prior grant[4] in which a series of videotapes was developed to supplement thermodynamics instruction. The primary target audience for *ThermoNet* is engineering students of sophomore level taking a first course in thermo. Secondary audiences include more advanced students or practicing engineers requiring a review of fundamentals, and teachers (especially for use as a lecture-enhancement resource). The principal content elements fall into three basic areas:

- Interactive learning resources, which include graphics-rich tutorials and interactive example problems to enhance understanding of thermodynamic principles and concepts,
- Tools, including extensive property tables with a built-in interpolator and links to other data sources, and
- Enrichment resources, including pictures and explanations of thermodynamic applications and historical bases of thermodynamics, and links to other useful and interesting sites.

Additionally, the *ThermoNet* project includes a significant effort in learning research which is exploring the use of online site-tracking, as well as other more conventional instruments, to evaluate how engineering students use hypermedia for mastering difficult cognitive tasks such as understanding thermodynamics.

ThermoNet is a work-in-progress which is in its initial stages of implementation. The following sections describe the design of the *ThermoNet* site, its current content, design of the evaluation process and some initial results of the evaluation effort.

Site Design

During the design phase of *ThermoNet*, the core production team developed an organizational scheme intended to create a user-friendly environment for the users as well as a site-structure that would lend itself well to systematic evaluation. *ThermoNet's* home page and the navigational scheme were designed based on interface design literature[5] and enhanced based on students' feedback during the prototype stage. It was determined that it was essential for students to have access not only to the tutorials through the home page, but also to the example problems, tables, resources, supplemental links, and a site map. A diagram of the overall site structure is shown in Figure 1.

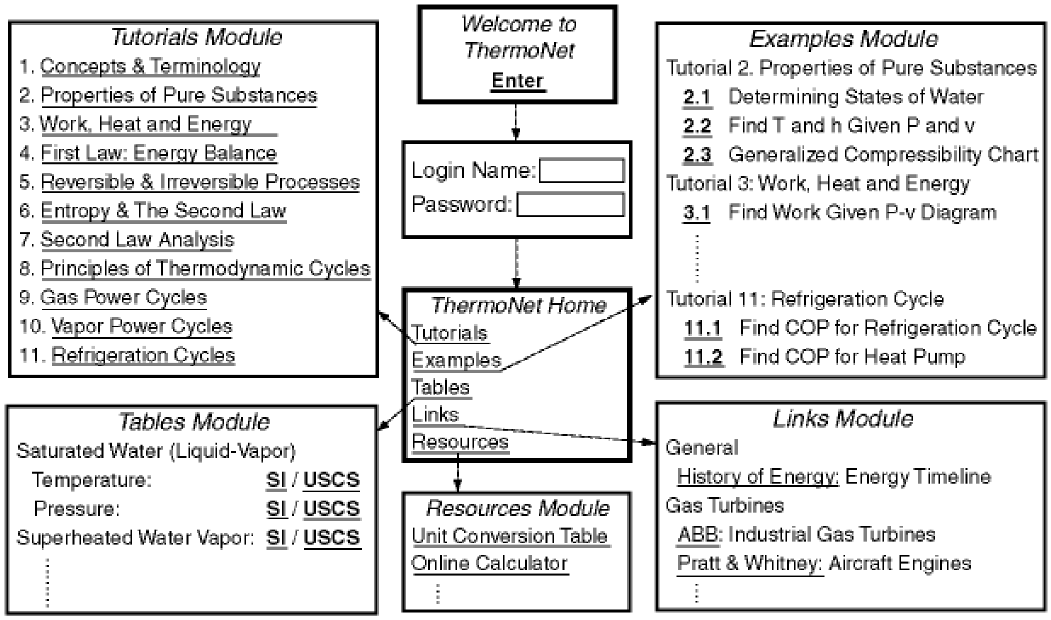


Figure 1 - Overall *ThermoNet* Site Structure

ThermoNet is accessed through an entry page that welcomes the user to the site. Access to the home page presently requires users to enter a username and password. During the development of *ThermoNet*, access has been limited to thermodynamic students at The University of Texas at Austin and the login system has been used to gather data on how the site is being used by specific students. Once the evaluation studies are completed, the login system will be abolished and the site will be open to anyone with a web connection.

The individual pages in *ThermoNet* are grouped into five modules: Tutorials, Examples, Resources, Tables and Links. The “Tutorials” module is currently the most thoroughly developed, with eight tutorials completed and three partially complete. The tutorials are designed to teach general thermodynamic concepts, with each tutorial roughly corresponding to a chapter in a traditional thermodynamics textbook. The “Examples” module contains both interactive and passive (non-interactive) example problems. Eventually all of the passive problems will be made interactive. The examples focus on developing a systematic methodology for problem-solving and on applying the thermodynamic concepts developed in the tutorials to problems. The “Resources” module currently contains only an online calculator and unit conversions table, but is intended to be filled-in with video clips and other media resources. The “Tables” module contains thermodynamic property tables with an online interpolator. The online interpolator requires students to locate the appropriate property table and enter all the data required for a linear interpolation. The “Links” module is also under development and will serve as a supplementary resource where users can link to other thermodynamic sites on the web.

Navigational paths around the site are being developed and refined as the site grows. An appropriate balance is being sought between making the navigation routes consistent and intuitive and keeping the overall system manageable so future navigation problems are minimized as the site evolves and grows more complex. The home page serves as the main crossroad for navigating the site. It is a page that is intentionally kept simple, containing links only to pages that list the detailed content of each module. In general, to navigate between unrelated pages in different modules, a user must pass through the home page. Once inside a given module, links to other modules are kept to a minimum and are included only when the contents of two pages are closely related.

The navigation system is most refined for the tutorials. Each tutorial contains 4 to 20 pages that are intended to be accessed linearly. The navigation system used in the tutorials encourages a sequential progression. Each tutorial is entered through its Contents page, where the major topics covered in the tutorials are listed as hot links. The primary navigation buttons on this page move the user to the first page of the tutorial. Once inside a tutorial, each page has a stationary window at the top containing a navigation bar and a navigation button at the bottom that links to the following tutorial page, as shown in Figure 2.

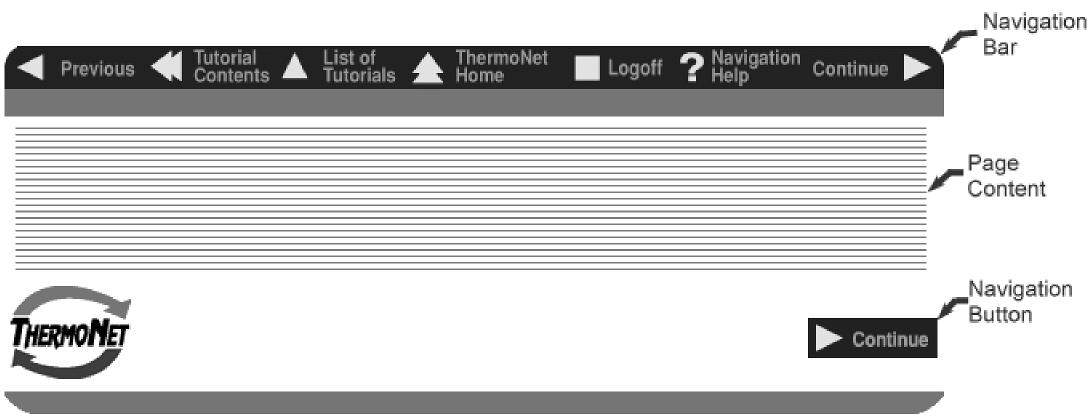


Figure 2 - *ThermoNet* Navigation Bar

The navigation bar allows the user to move forward or backward one page, or move to the tutorial's Contents page, to the page listing all of the tutorials or to the *ThermoNet* home page. A navigation help button is also provided that opens a pop-up box displaying a diagram illustrating where each of the navigation buttons leads and how these pages are related. Where appropriate, there are links within the tutorials to relevant example problems contained in the "Examples" module; these same example problems contain links back to the appropriate tutorials. The content in the "Resources" module will also be linked to or embedded in the tutorials as the this module is further developed. In the future, links to relevant web pages outside of *ThermoNet* will also be selectively integrated within the tutorials.

Examples of Site Content

In general, *ThermoNet* pages have been designed with the following guidelines in mind:

- Avoid long passages of pure text;
- Begin pages and illustrate concepts using graphics; include at least one graphic per page;
- Avoid simply stating key concepts; rather teach the concept using multiple choice questions that require the student to interpret a graphic and interact with the computer to answer;
- Keep pages as simple and short as possible; move long derivations and supplemental information into pop-up boxes; and
- Keep theory close to the real world with pictures and links showing practical applications.

The application of these guidelines will be illustrated by looking at two sample tutorial pages and an interactive example problem. The pages selected here are relatively short and easily represented in print. Many of the tutorials in *ThermoNet* include complex animations which, of course, could not be properly illustrated in this paper. Figure 3 shows a sample page from the tutorial “Entropy and The Second Law”.

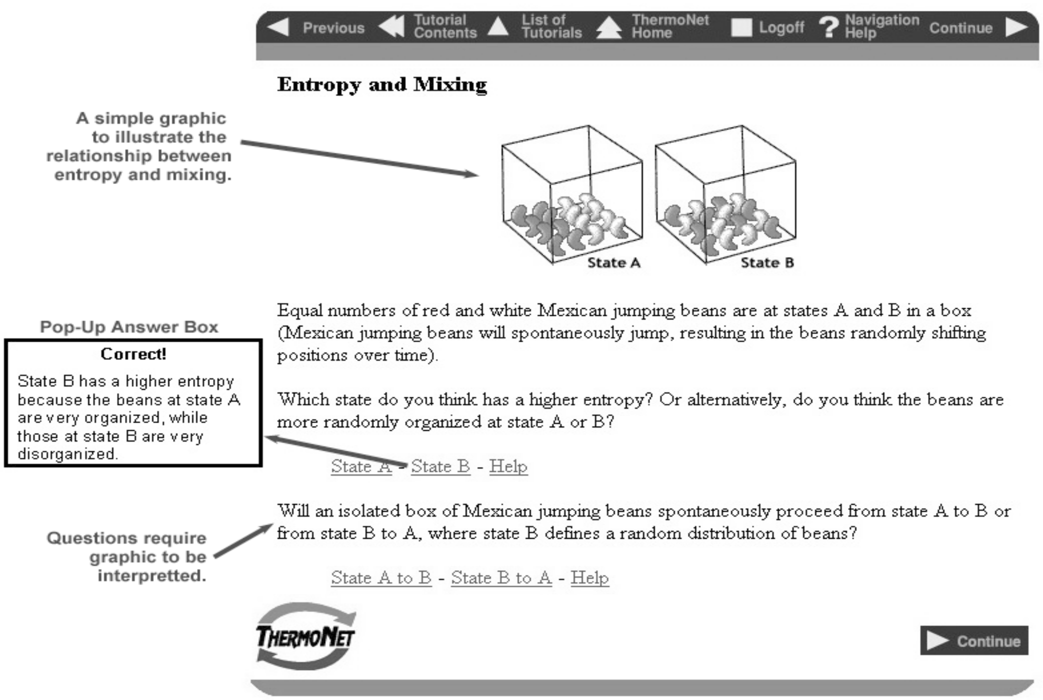


Figure 3 - Sample Tutorial Page on Entropy

The concept of entropy as a state property is introduced over a series of pages. The goal of these pages is to develop an intuitive understanding of entropy as a measure of randomness. Each page begins with a simple graphic showing control masses at different states. Students are first asked to choose the state with the higher entropy, which requires them to interpret the graphic and interact with the computer. If the student is unsure of how to quantify the entropy in the two states, a help button is available that opens a pop-up box describing how to interpret the graphic with regard to differences in entropy. Next, the student is asked whether the control mass would spontaneously proceed from state A to B or from B to A. This second question lays the foundation for the section on the Second Law, which immediately follows. In the

Second Law section these same examples are revisited but the graphics become animated, proceeding spontaneously from the low to high entropy state with an entropy bar graph showing how the entropy increases as the process proceeds.

Figure 4 shows a sample page from the tutorial "Analysis of Thermodynamic Cycles".

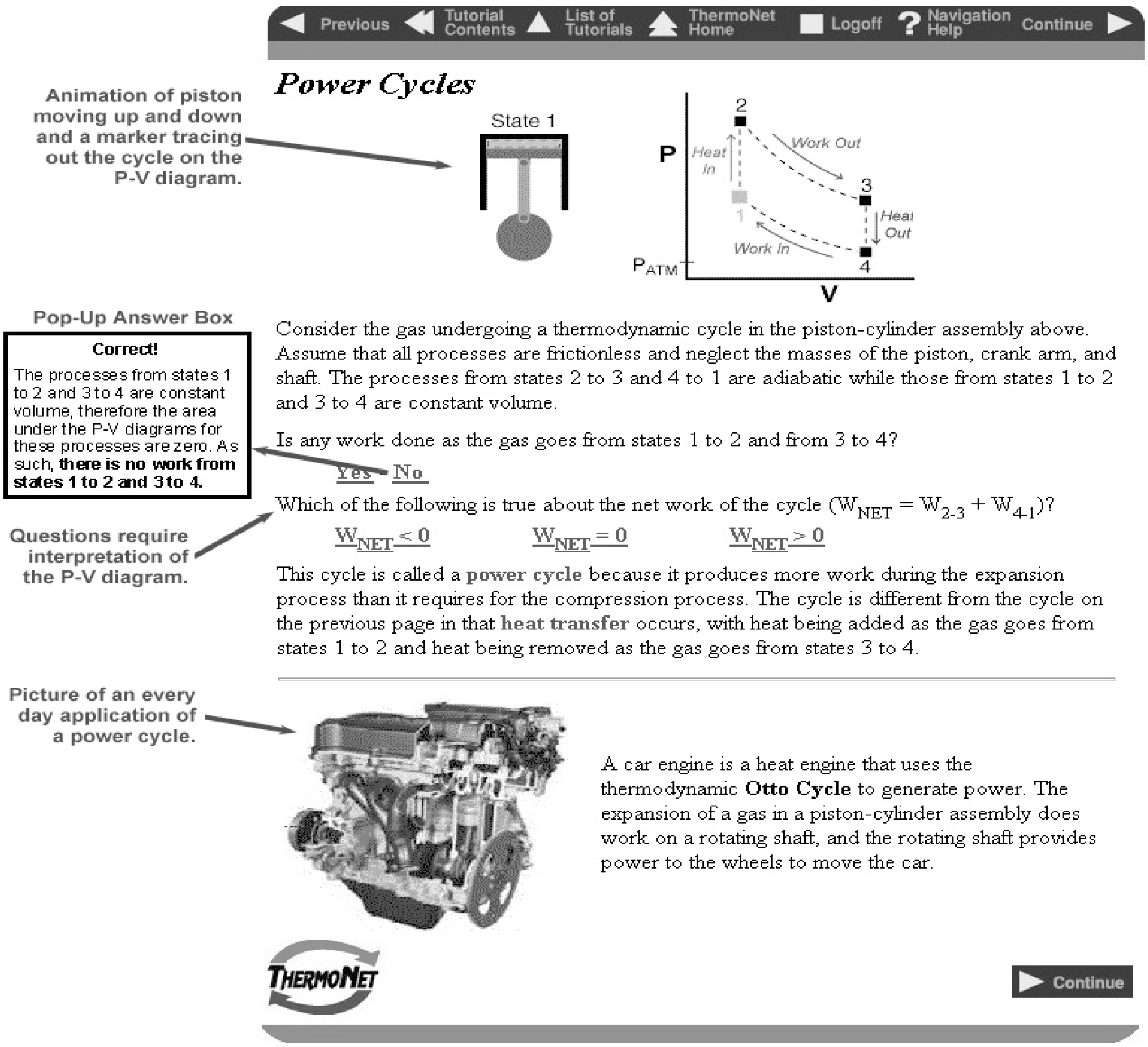


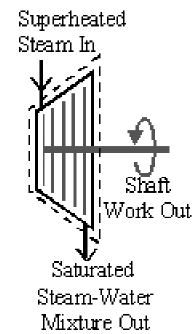
Figure 4 - Sample Tutorial Page on Thermodynamic Cycle Analysis

At the top of the page is an animation of a gas inside a piston-cylinder assembly undergoing a power cycle, with the cycle being traced out on a P-V diagram. The previous page introduced the concept of net work for a cycle and reviewed that the area under the P-V diagram represents the work for a process. On this sample page, the student needs to apply this knowledge to interpret the P-V diagram, realizing that the constant volume processes shown on the P-V diagram produce no work, and that the cycle produces positive net work. Finally, a picture of an automobile engine, a power cycle that actually uses a piston-cylinder mechanism, is shown to connect the abstract concept of a cycle to a familiar real-world application.

Figure 5 illustrates a typical interactive example from the "Examples" module.

Key words linked to pop-up boxes with definitions and pictures.

Problem Statement: Steam flows steadily through an **adiabatic turbine**. The inlet conditions of the steam are 10 MPa, 450°C, and 80 m/s, and the exit conditions are 10 kPa, 92 percent quality, and 50 m/s. The mass flow rate of the steam is 12 kg/s. Determine the power output (MW).



Given: ....

Justification for assumptions contained in pop-up boxes.

Find: $\dot{W}$ in MW

Assumptions: 1. Neglect changes in potential & kinetic energy
2. Assume Steady-Flow, Steady-State

Relevant portions of property data tables contained in pop-up boxes.

Solution: Using the superheated steam tables for state 1 and the saturated steam tables for state 2 (**bold values are given in the problem statement**)

State	P MPa	T °C	x	v m³/kg	h kJ/kg
1	10	450	-	0.02975	3,240.9
2	0.010	-	0.92	-	2,393.2

Interaction using multiple choice questions with answers in pop-up boxes.

Applying **Conservation of Mass**, does $\dot{m}_i = \dot{m}_e$?

Yes - **No**

The First Law:

$$\sum \dot{Q} - \dot{W} + \sum \dot{m}_i \left(h + \frac{V^2}{2} + gz \right)_i = \frac{dE_{CV}}{dt} + \sum \dot{m}_e \left(h + \frac{V^2}{2} + gz \right)_e$$

Lengthy derivations in pop-up boxes.

reduces for this problem to

$$\dot{W} = -\dot{m}\,(h_2 - h_1)$$ Derivation

Inserting numbers yields

$$\dot{W} = -12\,\frac{kg}{s}\,(2393.2 - 3240.9)\,\frac{kJ}{kg} = \underline{\underline{10.2\,MW}}$$

Comments: ....

Figure 5 - Interactive Example Problem

This module presently contains approximately 30 example problems, some of which have been made interactive while others still remain passive. Developing a consistent format for example problems has been challenging due to wide variations in length and content. For continuity, each example problem has been put on a single page containing "anchor" links to access various parts of the problem, rather than using multiple pages. As a result, pages for the more involved problems, such as cycle analyses, can get quite long. However, several techniques have been applied uniformly to all the example problems. In general, the problem is broken down into six sections to emphasize a systematic approach to problem-solving. The sections consist of the problem statement, designation of known ("given") information, specification of desired ("find") results, statement of assumptions, solution, and interpretive comments. Our approach to developing interactive example problems is to start with a passive example and then move as much of the supporting information as possible into pop-up boxes (such as long derivations), leaving only the heart of the problem on the main page. Supplemental information is then added using more pop-up boxes, such as definitions for key vocabulary words, pictures of real components, and property tables. For example, a flow diagram of a refrigeration system was created as an image map so that clicking on the compressor symbol opens a pop-up box containing a physical description of a compressor and a picture of a real refrigeration compressor. Equations are also often presented as image maps so that clicking on a particular term (shown in blue to indicate hypertext) brings up information on that particular term, such as whether it can be neglected or why it does or does not apply to the present case. In many instances, multiple choice questions have been integrated into the problem. The example shown above is an abridged version of an online problem, with the "Given" and "Comments" sections removed to save space. Although abbreviated, it does illustrate most of the key features of the longer example problems.

Data Acquisition and Evaluation

When developing a web-based instructional environment, it is imperative to continuously assess how the medium is being used and its effectiveness. An important element in the development of *ThermoNet* is the collection of detailed use data by the server as users traverse the site. Such usage-pattern data, along with learners' profiles obtained with conventional survey instruments, serve as an important tool both in guiding development and determining the effectiveness of the web-based medium as an instructional tool.

Students' "audit trails" in *ThermoNet* were monitored automatically and unobtrusively through the server. Each page of *ThermoNet* is stored in a hierarchical position in the folders of the server. For example, all tutorials are stored in a "Tutorials" folder while all example problems are stored in an "Examples" folder. When a link is activated, the user jumps to a new html page that ends with the suffix "index.html", automatically triggering the recording of a "hit" in the server's chrono file. As a user traverses the environment, every mouse-click on a link– from downloading graphics to stepping to a new page – is recorded. Information on the identification of the users, their IP addresses, and the time and date of usage are also recorded. This data is retrievable from the server by the evaluator and the consistent storage scheme allows the evaluator to determine the time a user spends on the site as well as the specific content elements the user is accessing.

In addition to the usage data collected through the server, a questionnaire was developed and administered to students over several semesters. The course questionnaire was designed to obtain information on student demographics, learning characteristics of the students taking the course, characteristics of the students using the site, and student needs and perceptions. While *ThermoNet* was being designed, the questionnaire was given to students who did not yet have access to *ThermoNet* to obtain a baseline on their personal demographics, their computer experience and use, their preferred method of learning thermodynamics, and possible enhancements to the thermodynamics course. In subsequent semesters, the questionnaire was administered to larger populations of students; the last group had access to *ThermoNet* while the prototype was being developed. Over ninety-one percent of the students ranked themselves as computer literate and as using computer applications on a frequent basis, suggesting (not surprisingly) that having a supplementary web site for the course and asking or requiring students to use it is feasible.

In surveys administered during summer 1997, an overwhelming number of students felt that their understanding of thermodynamics would be enhanced through availability of more example problems, and about half of the students indicated that the use of videos would also enhance their learning. Subsequent surveys indicated that a majority of students found the biggest challenge to learning thermodynamics was the need for more example problems both in the lectures and in the textbook. In studying for tests, they reviewed the notes and solved additional example problems. They overwhelmingly agreed that graphics and other visual media would provide better mental pictures of processes and felt that they could learn more efficiently and effectively with access to more graphical and pictorial material. They also indicated a desire for access to interactive computer-based tutorials focused on fundamental thermodynamic principles as well as computer simulations of thermodynamic processes. Students expressed a desire for better online communication with instructors and other students and access to course information. Finally, a large majority expressed the view that a computer-based resource would enhance their approach to learning thermodynamics. Such information played a significant role in the design of *ThermoNet,* in terms of what to include and how, and in helping to make*ThermoNet* more useful.

Student profiles were also analyzed with respect to their use of *ThermoNet* and to their academic achievement (as measured by their GPA's). Specific student characteristics such as their classification as a verbalizer or visualizer, their goal orientation, their academic achievement, and the amount of time they spent on task were used to group the students and determine whether there was any impact due to the supplement of web-based instruction. The students were classified using two standard assessment instruments, the Revised Verbalizer-Visualizer Questionaire [VVQ], the Patterns of Adaptive Learning Survey [PALS], and the amount of time they used *ThermoNet*.

The students' learning preferences were measured by the VVQ. One of variables in the evaluation of *ThermoNet* was the amount of time students accessed visual elements. The use of visual media that are not available in traditional instruction is relatively easy to implement in a web-based environment. Learning abstract concepts in thermodynamics is enhanced with animations and graphics, a resource previously not readily available to students studying thermodynamics.

The students' goal orientation was measured by an adaptation of the PALS. Through the survey, the students were classified as having a task, performance-approach, performance-avoid, or extrinsic goal orientation. By analyzing the relationships between the students' goal orientation, the actual amount of time they spent using *ThermoNet* and their academic achievement, more insight can be developed into the most appropriate way to use ThermoNet in the overall teaching environment.

The amount of time an individual uses a supplement to conventional instruction may impact the value of the instruction to the particular individual. Therefore, in order to determine whether the classification of a learner's goal orientation affects the quantity of her access, the amount of time the learner uses the site was tracked by the server.

Comprehensive evaluation of one semester's data collected by these various methods is still in the early stages, but some preliminary results are interesting and suggestive of further lines of study. The data obtained to date indicate that the time students spent in using *ThermoNet* was not closely correlated with their academic achievement . However, there appeared to be a significant relationship between the student's goal orientation and their subsequent course performance. Students with a performance-approach goal orientation focus on demonstrating and proving competence. This category of students demonstrated higher achievement in their thermo course. On the other hand, students who have a performance-avoid goal orientation focus on avoiding the demonstration of lack of competence. These students demonstrated a lower level of performance.

One interesting (and somewhat disconcerting) result was the apparent existence of a significant inverse relationship between a student's goal orientation and the time engaged in the web-based instruction environment on the student's level of course performance. With time entered as a variable in a multiple regression analysis, the data suggest that time spent using *ThermoNet* may have had a negative impact on students' performance. In the questionnaire conducted at the end of the course, the majority of students indicated that there was not enough time allotted to the course as a whole to spend additional time using supplemental resources, such as *ThermoNet*., in addition to the required textbook, lectures and problem assignments. One hypothesis, therefore, is that students who spent a lot of time with *ThermoNet* may did so at the expense of other activities (such as reading the textbook and working homework problems) which more directly impact their performance on tests and hence their course grades. This is clearly a question that merits further study, and it underscores the need to integrate new learning resources like *ThermoNet* into a complete teaching strategy.

Conclusions

Hypermedia learning environments, especially those deliverable over computer networks, have significant potential to enhance engineering instruction. *ThermoNet*, an early experiment in design and delivery of online instruction in the area of engineering thermodynamics, is not intended as a substitute for conventional textbooks and traditional learning methods, but rather as a supplemental tool to help students understand difficult concepts and improve their ability to apply them to practical problems. Initial student reaction to the site has been favorable, but quantitative data on the learning effectiveness of this online resource are still sparse and what little data we have obtained suggest that to be effective, its use must be integrated in a complete system of instruction.

References

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