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Teaching efficacy of Web-based teaching methods in an undergraduate thermodynamics course

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ABSTRACT: An online version of a physical steam turbine experiment was developed for use in an undergraduate thermodynamics course in the Mechanical and Aerospace Engineering Department at San José State University, San José, USA. The online simulation was motivated by the need to illustrate theory-based lecture content with real-world applications and the need to efficiently serve a large class, among other factors. The implementation was accomplished with JavaScript and HTML, as well as other commercially available software for Web-based applications. The Web-based assignment was shown to be more effective than a traditional problem set at teaching the thermodynamic concepts discussed in lecture without a significant increase in time required of the instructor for administration and grading.

INTRODUCTION

A growing number of institutions have been implementing Web-based, interactive experiments into their existing courses in a variety of subjects. For example, a Web-accessible, virtual laboratory was implemented for an introductory-level engineering class at Johns Hopkins University as a solution to an over-registered class [1]. Java applets were used to illustrate scientific phenomena and pose real-world engineering questions. This approach has also been used to teach abstract concepts in structural analysis at National Chiao Tung University [2]. A written test conducted before and after the virtual journey showed that the students involved acquired basic knowledge of structural analysis from the exercise. Comprehension and application of structural analysis, in addition to basic knowledge, were also tested.

The literature indicates that there are unique teaching advantages associated with an interactive Web-based teaching approach. Web-based assignments allow for additional perspectives not possible in a laboratory setting, allow the learner to proceed through an experience during a broad time period not fixed by a regular class schedule, and makes learning more interesting [3]. Lastly, an interactive simulation of an environmental engineering design project was shown to be an effective way to supplement theory-based course content without increasing student loads or placing excessive time demands on the instructors [4].

MOTIVATION

The undergraduate thermodynamics course in the Mechanical and Aerospace Engineering Department at San José State University (SJSU), San José, USA, is a 4-unit lecture course with no concurrent laboratory course. It is a required course for Mechanical and Aerospace Engineering majors. There are typically between 60 and 80 students enrolled per semester. The following are some of the factors that prompted the development of the interactive Web-based assignment.

The Need to Illustrate Theory

Because thermodynamics is an abstract subject with many non-intuitive concepts, it is less intimidating and easier to understand when real-world applications of the theory are provided. Traditional problem sets of hypothetical engineering scenarios are often assigned for this purpose. However, a large percentage of engineering students are visual, sensing and active learners [5]; it is necessary for them to see and experiment with things before they can fully understand engineering concepts. An interactive illustration of a physical thermodynamics experiment on a computer screen could fulfil this purpose. The operation of the experiment could be shown with photographs and videos, and a graphical interface could be developed to provide a self-guided virtual tour through the assignment.

The Need to Serve a Commuter Campus

Because most SJSU students live and work off-campus, the convenience of a Web-based assignment is of great benefit. A Web-based assignment can be accessed anytime from any location with Internet access, unlike a physical laboratory experiment or a problem session. In comparison, the logistics involved in scheduling laboratory sessions to demonstrate an experiment for a large class are often prohibitive.

The Need to Accomplish More with Less in a Crowded Curriculum

SJSU degree programmes are faced with a number of conflicting demands, such as a large number of required general education courses, political and societal pressures to help students graduate in four years, and the need to modernise the curriculum to reflect the latest technological advances. The Web-based approach offers a way to introduce visual and experimental teaching tools into existing courses without increasing time demands on instructors or students.

The Need to Incorporate Modern Teaching Tools

Because the Internet is a way of life today that was unimagined even ten years ago, most college students are proficient at navigating and finding information on the Web. Online engineering assignments leverage this trend as they connect textbook theory with a convenient source of information, should the desire to undertake further research develop.

Safety and Cost Considerations

Other considerations include the safety and low cost of a Web-based assignment. The dangers associated with boiling, condensing and combusting substances often used in thermodynamics experiments are eliminated with a computer simulation. Lastly, costs, such as facilities, technician support, maintenance, supplies and student laboratory assistants, are not required for this type of approach.

The use of Web-based experiments has the potential to reinforce the learning of abstract subject matter more effectively than the traditional approach of lecturing and assigning problem sets. While it will never duplicate the *hands-on* aspects of a physical laboratory experiment, it could offer many of the same benefits and has its own unique advantages from a teaching perspective.

To determine the most effective way to incorporate this approach into an existing course, a Web-based thermodynamics assignment was developed based on an existing steam turbine experiment and introduced into the undergraduate thermo-dynamics course at SJSU. The learning objectives were assessed through an assessment survey, performance on the assignment and student feedback. By determining which learning objectives were most effectively accomplished with this approach, conclusions on the most suitable use of this teaching tool can be determined for the development and use of future Web-based assignments.

SCOPE

The scope of the Web-based steam turbine assignment encompassed the following goals and learning objectives:

- Reinforce theory through steam turbine analysis. The learning objectives for accomplishing this goal include: using thermodynamic charts to obtain steam properties, performing mass and energy balances on steady-flow components, and calculating isentropic efficiency. Students are then expected to reflect upon the calculated results to obtain a general understanding of how to measure and influence the power output of a steam turbine.
- Provide real-world examples of components and sensors. In lecture, steam turbines and sensors are presented only as schematics. Interactive photographs and videos, although they do not replace actual hands-on experience in the laboratory, bring students closer to the actual hardware.
- Provide training in experimental uncertainty. Textbook problems usually have a preferred methodology and a unique right answer, unlike real-world problems that are often subject to measurement uncertainties and non-ideal conditions. Students need to appreciate the engineering judgement needed to account for such factors.

DESIGN AND IMPLEMENTATION

The design of the Web-based assignment considered the motivation for this project and the type of interactive features that would accomplish the learning objectives. The information gained from the prior literature about the teaching efficacy of various virtual reality techniques was also considered. There is an abundance of software tools available to implement interesting interactive Web sites. It was decided to use HTML and Javascript to implement interactive photographs and *Quicktime Pro* to implement a virtual reality movie of the apparatus.

The interactive photographs were designed to address the goal of providing real-world examples of components and sensors described in the lectures. The labelled schematic of the apparatus shown in Figure 1 was displayed side by side with the photograph in Figure 2. As shown in these figures, steam is routed first through a turbine and then through a heat exchanger cooled with water. A dynamometer is used to measure steam turbine performance. As the mouse is rolled over components and sensors in the schematic, the corresponding part in the photograph is highlighted. This serves to identify parts, explain how components are connected and show where the sensors are located.

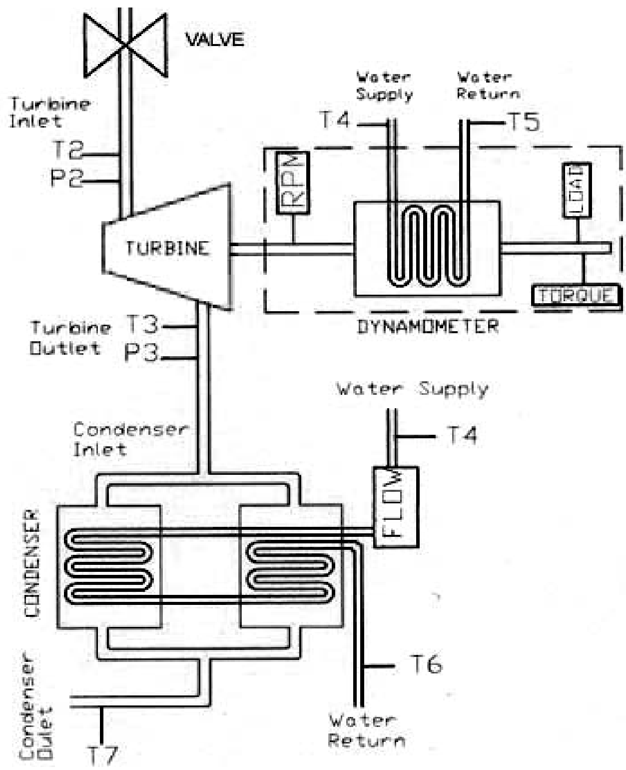

Figure 1: Labelled schematic of a steam turbine.

A rotatable apparatus was implemented to further address this goal using the *Quicktime Pro* Virtual Reality module. In this feature, the user can click and drag a photograph of the apparatus to rotate it as if he or she were walking around it. In addition, the user can zoom in or out of any particular view. Furthermore, select views are labelled if there are components of particular importance or interest. For example, a labelled side view of the apparatus is shown in Figure 3.

Figure 2: Photograph of the steam turbine experiment.

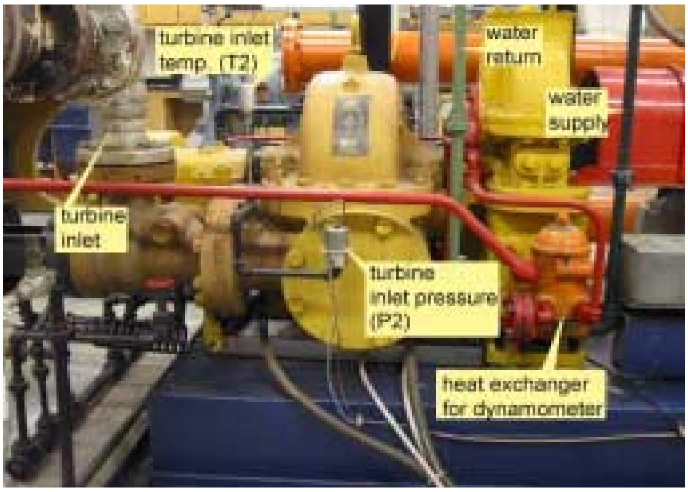

Figure 3: Labelled view from rotatable apparatus.

Sources of experimental uncertainty were reflected in the assignment by imitating the actual sensor outputs in the experiment. The fluctuating components of measurement uncertainty were recorded during data acquisition and implemented in the Web-based assignment using the random number generation feature in JavaScript. As a result, the Web-based data vary slightly from one reading to the next, as they would in real life. Students then learn the value of averaging multiple samples to obtain a more representative measurement. In addition, the pressure sensor located at the inlet to the steam turbine exhibited a slight offset error that implied a sub-cooled liquid in one of the six required cases. Students are then called upon to re-examine the experimental set-up and speculate why the readings appear to be inconsistent. The use of this kind of engineering judgment is lacking from traditional problem sets, which tend to make idealisations and assumptions in order to eliminate inconsistencies.

Data analysis required of students focused on reinforcing the techniques of mass and energy balances, determining phase and properties using steam tables, and calculating the isentropic efficiency of the turbine and its significance. The load and Revolutions Per Minute (RPM) of the turbine are varied using the dynamometer, and the resulting torque and flow measurements are used in the calculations. There were six cases in total, each requiring the determination of the properties of superheated, saturated and sub-cooled water, energy balances on the turbine and heat exchanger, and calculation of isentropic efficiency. Graphs of power output versus the input parameters were required, as well as a write-up of the experimental procedure and an analysis of the results.

Links to related Web sites, such as steam property calculators, unit conversion calculators, animated steam engines and history of steam power, were bundled with the Web-based assignment to spur further interest in the topic. Having the assignment on the Internet makes this route of obtaining further information seamless and fun.

ASSESSMENT

The teaching efficacy and the appropriateness of the learning objectives for this type of assignment were assessed with the results of an assessment survey, student performance in the assignment and anecdotal feedback. The Web-based assignment was shown to be more effective at accomplishing the learning objectives in comparison to traditional problem sets.

During the spring semester of 2003, the undergraduate thermodynamics class at SJSU was given the choice of completing either the Web-based steam turbine assignment or a problem set that covered the same lecture topics. Otherwise, the lectures, problem sessions and available office hours were identical. The lecture topics covered were: mass and energy balances on steady flow components, such as turbines and heat exchangers, determining phase and properties using the steam tables, and calculating isentropic efficiencies for steady flow components. Of the students for which a full set of assessment data were collected, 33 chose to undertake the problem set and nine chose to do the Web-based assignment. It is unclear why so many more students chose to do the problem set. It is speculated that the problem set was perceived to be the *easier* assignment.

The assessment survey tested concepts covered by the lecture topics, as well as component identification and function. The survey was administered before and after the assignments to both groups. The questions and learning objective or goal tested are listed in Table 1. On each question, a score of 1 was given if correct and 0 if incorrect.

On the whole, both groups of students were roughly of comparable ability prior to the assignments. Figure 4 indicates general student understanding of these concepts before any assignments were given. The group of students who chose to do the Web-based assignment started out slightly stronger on Questions 1 (quantifying power output) and 2 (identifying components) and less strong on Question 4 (understanding isentropic efficiency) than those students who chose to do the problem set. The average scores on Question 3 (identifying components) and 5 (fixing steam states) were similar. There is no underlying pattern to the strengths and weakness of either group; therefore, it is concluded that the apparent advantage of the Web-based assignment group is slight.

However, it is clear that the Web-based assignment was more effective at teaching the concepts tested by the assessment survey than the problem set. Figure 5 compares the average scores on the assessment survey after the assignments and clearly shows that the Web-based assignment group outperformed the problem set group on every question. A comparison of Figure 5 with Figure 4 shows that the Web-based assignment group improved on Questions 2 through 5 with perfect scores on Question 3. The problem set group improved less dramatically on Questions 2 and 4, and did worse on Questions 3 and 5. The fact that both groups did worse on Question 1 by a similar amount suggests that the timing of lecture topics with the administration of the assessment survey may have contributed to a misleading interpretation of that particular question.

Table 1: Assessment survey questions for Web-based steam turbine assignment.

No.	Question	Learning Objective/Goal
1.	The power output from a turbine is proportional to: a) isentropic efficiency; b) torque; c) torque times RPM.	Measuring and quantifying power output.
2.	Identify the following components: (photographs of a torque sensor, heat exchanger, and pressure gauge follow).	Component identification.
3.	What does a dynamometer do?	Component identification.
4.	What does an isentropic efficiency of 90% mean?	Understanding isentropic efficiency.
5.	Which properties are sufficient to fix a state in the vapor dome? a) temperature and pressure; b) temperature; c) enthalpy and pressure; d) temperature and quality.	Using steam tables to find properties and phases.

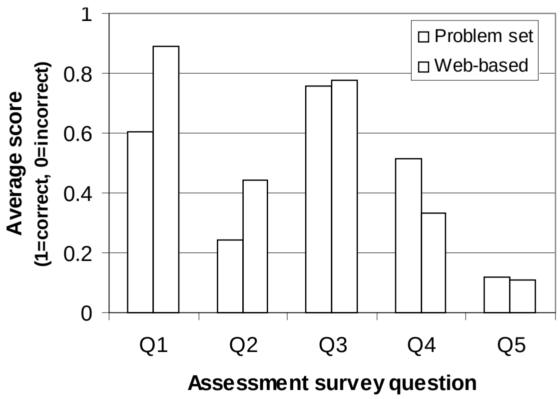

Figure 4: Comparison of average scores on assessment survey before assignments.

The average score on the Web-based assignments was slightly higher than on the problem sets. Both assignments were graded out of 100 points and counted for 15% of the final class grade. The average scores were 88% and 80% for the Web-based assignment and the problem set groups, respectively.

The goal of providing training in experimental uncertainty in real world applications was met by the Web-based assignment and not assessed in the problem set due to the nature of the two assignments. A discussion question on the Web-based assignment asked students to ponder sources of measurement uncertainty and resulted in answers such as sensor offsets, fluctuations in the experiment, variation in atmospheric conditions and human error.

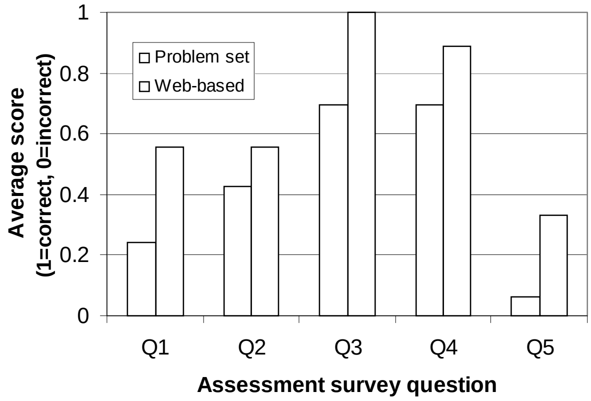

Figure 5: Comparison of average score on assessment survey after assignments.

The Web-based assignment seemed to be more enjoyable than the problem set based on anecdotal student feedback received through the Web site, by e-mail, and informal discussions. In general, comments from the Web-based assignment group remarked how rewarding it was when the process diagrams and isentropic efficiency graphs in their textbook were duplicated with real-world data, despite the tediousness of the calculations. Both groups complained of the length of the assignments, although this subset of students was primarily composed of those that did not start the two-week assignment until the last minute.

CONCLUSIONS

The results of this teaching study show that the interactive Web-based thermodynamics assignment described here was more effective at reinforcing theoretical concepts discussed in a lecture setting compared to a more traditional problem set. In addition, the valuable concept of experimental uncertainty was addressed with the Web-based assignment unlike a traditional problem set.

Because the time required by the instructor to administer and grade an assignment were similar for both, it is concluded that the Web-based assignments are a more effective teaching tool for the type of learning objectives tested. Replacing problem sets with this type of assignment is justified by the added teaching efficacy and benefit to students when the initial development time is available to the instructor.

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