AC 2011-896: ASSESSING AND UPDATING AN UNDERGRADUATE THERMO-FLUIDS LABORATORY COURSE

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Assessing and Updating an Undergraduate Thermo-Fluids Laboratory Course

Abstract

A required course for mechanical engineering students at South Dakota State University is Thermo Fluids Laboratory. The purpose of this one-credit course, usually taken in a student's last semester before graduation, is to enrich the student's understanding of thermodynamics, fluid mechanics and heat transfer principles in an experimental laboratory setting. The Mechanical Engineering Department at SDSU recognizes the importance of laboratory coursework in the curriculum, so a project was undertaken to improve student learning outcomes from this course. The goals of this project were to formally assess how well the current Thermo Fluids Laboratory course achieves the desired course outcomes and to update the course content and equipment based upon the findings of the assessment.

An online survey tool was the method chosen to solicit, collect, and assess the opinions of students who had recently taken the course and of the instructors who had taught the course during the past several years. Thirteen of the students who had taken the course in Spring 2010 and six recent instructors of the course responded to the survey. From the surveys, it was evident that the students had difficulties linking the concepts of the laboratory course to the lecture courses of thermodynamics, fluid mechanics and heat transfer. All of the students mentioned the operational condition of the equipment as a significant problem. In addition, the lack of computer data acquisition equipment was another complaint frequently mentioned by the students. Therefore, the majority of the students surveyed did not feel the course significantly contributed to their learning in the Mechanical Engineering Program. Similar concerns were recorded in the survey of the former instructors.

Based on the survey results, changes were implemented in an attempt to improve the content of the course, the condition of the equipment, and the relevance of the lab exercises to the rest of the thermo-fluids curriculum. Funds were obtained to purchase a computer data acquisition system for use in the course. The course changes included revision of the series of experimental topics, written report formats, and laboratory group activities. At the end of the Fall 2010 semester, ten students responded to the same survey given to the Spring 2010 students. Although the sample size was small, the comparison of the survey results shows that the changes improved the course significantly.

1. Introduction

In the National Academy of Engineering's *The Engineer of 2020: Visions of Engineering in the New Century*[1], strong analytical skills, practical ingenuity, creativity, good communication skills, mastery of the principles of business and management, leadership, high ethical standards, a sense of professionalism, dynamism, agility, resilience, flexibility, and an attitude of lifelong learning are identified as attributes that will be required of successful engineers in the 21st century. Many of these attributes, including practical ingenuity, creativity, and communication skills, are perhaps better learned in an applied, hands-on environment such as an undergraduate engineering laboratory than in lecture-based coursework. Feisel and Peterson[2] state that although

it has never been suggested that laboratories be forgone in engineering education, they have been taken for granted at times. It is of great importance, therefore, for engineering faculty to become proactive to ensure that the laboratory courses are conducive and effective in fulfill their mission of teaching students these and related skills.

ME 476: Thermo Fluids Laboratory is a required course for mechanical engineering students at South Dakota State University. The purpose of this one-credit course, which is typically taken a mechanical engineering student's final year before graduation, is to reinforce his or her analytical skills in thermodynamics, fluid mechanics and heat transfer principles in an experimental laboratory setting and to effectively communicate the results of experiments.

After completion of ME 476, the mechanical engineering student is expected to be able to

1) apply the theoretical and analytical skills acquired in their thermodynamics, fluid mechanics, and heat transfer lecture courses to laboratory experiments,
2) apply proper experimental techniques and the proper use of instrumentation, and
3) present experimental results in technical writing and technical presentations.

The Mechanical Engineering Department recognized the importance and value of hands-on laboratory experiences in the undergraduate curriculum, so a project was undertaken to improve student learning outcomes from this course. The goals of this project were to formally assess how well the current Thermo Fluids Laboratory course achieves the desired course outcomes and to update the course content and equipment based upon the findings of the assessment.

The accomplishments of this project were as follows:

- Surveys of both recent students and recent instructors were used to obtain feedback from the stakeholders of the course and identify the issues most in need of improvement.
- The condition of the equipment present in the laboratory was assessed.
- Equipment maintenance and repairs were performed as necessary to improve reliability and allow greater exploration of the physical principles governing their operation.
- A state-of-the-art data acquisition system was specified and purchased.
- Several laboratory exercises which did not enhance the student learning outcomes were eliminated, allowing the expansion of the most effective laboratory exercises.
- The existing instructional material (lectures, pre-lab quizzes, etc.) were updated and enhanced to improve student participation and conceptual understanding of the thermo-fluids principles explored in the laboratory exercises.
- Surveys of students who took the course after the above-mentioned changes were implemented were used to assess the effects of those changes.

2. Survey Results

Separate surveys for the students enrolled in the course in the Spring 2010 semester and for instructors who have taught the course in the last five years were prepared. The surveys contained questions related both to the specific laboratory exercises performed in the course in recent semesters (listed and described in Table 1) and to the content and organization of the course as a whole.

Table 1. List of laboratory exercised performed in Thermo Fluids Lab, condition of the experiment equipment, and changes made between Spring and Fall 2010 semesters.

Lab	Condition	Changes
Conduction Lab – Contact resistance and the temperature dependence of thermal conductivity were investigated.	One thermocouple and one thermocouple signal wire were non-functional	Thermocouple and signal wire repaired.
HVAC Lab – A purpose-built air-conditioning experimental apparatus was used to investigate the operating characteristics and performance of an air-conditioning system.	Equipment functioned properly.	Data acquisition equipment used to automate large number of temperature readings.
Heat Recovery Lab – Performance of an enthalpy wheel heat recovery system was investigated.	In the most recent semester, the equipment for this lab failed to function correctly, so no data was collected.	Lab removed from course.
Compressor Lab – Performance of a single-stage reciprocating air compressor was investigated.	The apparatus is designed to investigate both single-stage and two-stage compression, but one of the compressors has not been operational for several semesters.	Maintenance performed on both compressors. Both stages now functional and used in exercise. Data acquisition equipment used to automate measurements.
1st Law Lab – Temperatures were recorded while water in an insulated container was heated with an electrical resistance heater and then cooled with ice. Adherence to the First Law of Thermodynamics (conservation of energy) was investigated.	Equipment functioned properly.	None needed at this time.
Air Flow Lab – The velocity profile of the flow in a diffuser was measured with a pitot tube. The effect of boundary layer growth under an adverse pressure gradient on the performance of a diffuser was investigated.	Equipment functioned properly.	None needed at this time.
Bomb Calorimeter Lab –Heat generated by combustion of a benzoic acid tablet was measured in a bomb calorimeter.	This lab was performed only once, with two students performing all of the tasks and providing the data to the rest of the class.	Lab removed from course.
Gasification Lab – The instructor demonstrated the operation of a gasification rig.	Because of the state of the apparatus, no data was able to be obtained.	Lab removed from course.

2.1 Student Surveys

Thirteen students who were enrolled in the in this course in the Spring 2010 semester responded to the student survey. Upon review of the survey results, the most frequent concern was the condition of the laboratory equipment. Several students noted that many of the laboratory exercises could not be completed or gave unreliable data due to the condition of the laboratory equipment. An example comment referring to the Heat Recovery Lab exercise was "The lab wasn't even performed. The apparatus was down, so an individual report was written on three different types of heat recovery systems."
Other results from the student survey suggested that the amount of work required of the students was slightly too much and the amount of guidance received from the instructor was too little. Several specific laboratory exercises were identified as not having clear objectives and/or not enhancing the students' conceptual understanding of theory. Some of the responses indicated that more discussion of the physical principles governing the operation of the equipment would have enhanced the educational value of the course.

2.2 Instructor Surveys

In addition to the student surveys, this project also surveyed the former instructors of the course. Six instructors who have previously taught the course responded to the instructor survey. As in the student surveys, the main issue mentioned in the instructor survey was the operational condition of the equipment. An example comment: "Many of these labs have good potential but they need further development, including improved equipment reliability and a more rigorous well-developed theoretical background and learning objectives to accompany the exercises." The Compressor Lab was specifically identified as having the potential to be a very useful and informative laboratory exercise if the equipment were working properly.

The majority of the instructors struggled to find adequate time to devote to preparing for each of the laboratory exercises. One example comment: "Unreliable or misconstrued operation of equipment led to some frustration and 'panic time.' In general I was most frustrated by a lack of personal time to devote to making positive changes." Another area identified for improvement was in data acquisition: "I would also be good to tie computer data acquisition into the course instead of manual readings. The industry uses technology to take the data, so it would be good for the students to get exposure to what's out there."

2.3 Identified Needs

The student and instructor surveys were of great value in determining the areas of the course in which changes would result in the greatest improvement of student learning outcomes. Of greatest importance was the inspection of the laboratory equipment and improvement of its operational condition. The purchase and integration of a computer data acquisition system was also of high priority. The surveys also suggested that the laboratory exercises that did not enhance the student learning outcomes should be eliminated and the best exercises expanded. The course materials should be reviewed and improved to give more thorough explanation of the theory behind the laboratory exercises and a more thorough description of their goals.

3. Equipment Improvements

3.1 Equipment Repaired

A primary concern cited by the students was the condition of the laboratory equipment. In order to assess the operational condition of the equipment, each laboratory apparatus was inspected and tested based on the procedures outlined for its respective lab exercises. Several of the experimental apparatuses were indeed not operating as designed, and maintenance and replacement of defective parts was performed. One example was the air compressor system used in one of the lab exercises (Fig. 1). The compressor system in the lab is composed of two compressors that can be independently controlled. The system was originally designed by a team of undergraduates as a senior design project. It was to allow for students to analyze air compression in four different modes: single-stage with Compressor 1, single-stage with Compressor 2, dual-stage without intercooling, and dual-stage with intercooling. However, in recent semesters only one of the compressors was operational, allowing the system to be run in only one of the four modes. The system was inspected and maintenance was performed on both of the compressors; as a result, both compressors are currently in operational condition. Additional effort was made to determine the conditions for which dual-stage operation is possible, and the compressor system can now be run in all four of the compression modes. Similar maintenance and repair was performed on all major equipment used in the course.

Fig. 1. Image of the Dual-Stage Compressor apparatus used in Thermo Fluids Laboratory

3.2 Equipment Purchased

A significant need identified in both the student and instructor surveys was the inclusion of hands-on experience with data acquisition systems similar to those used in research and industry. The Hewlett Packard (now Agilent Technologies) Benchlink system that has been used in this lab course in the past was an obsolete system that is no longer manufactured. Moreover, the system in the lab has been nonoperational for some time. Therefore, the students who have taken the class in the recent past have not been given the opportunity to use a computer data acquisition system.

National Instruments hardware was specified and purchased for this lab course and will form the basis of the lab's data acquisition system. National Instruments data acquisition systems are commonly used both by academic/government research laboratories and by many of the companies that will employ our students. In addition, it was found that, because of its use by other departments, SDSU has a site license for National Instruments LabVIEW™ software, which comprises the other part of the data acquisition system. The data acquisition system was connected to the thermocouples, pressure transducers, and mass flow meter of the air compressor apparatus, since several of the instruments cannot be read manually. The new data acquisition system will allow this lab to be again performed with full functionality. The data acquisition system was also used in the HVAC lab, which in the past had used ten mercury-in-glass thermometers for temperature measurements. The data acquisition system allowed those temperatures to be recorded in significantly less time, allowing for the investigation of a greater number of operating conditions.

4. Course Changes

4.1 Elimination of Laboratory Exercises

Because the course had in the recent past suffered from a lack of maintenance of the experimental apparatuses, the experiments students performed in any given semester were determined by what equipment was operational. This resulted in a set of experiments that may or may not have achieved the course objectives. A thorough examination of the laboratory exercises used in the most recent semesters was undertaken for this project. Important considerations were the relevance of the labs to the thermo-fluids concepts important in mechanical engineering and enhancement of the students' qualitative understanding of the thermo-fluids theory and quantitative skills from the lab exercises. The cost and difficulty of upgrading the improperly functioning equipment was taken into consideration, and the instructor survey comments were used as a reference in making choosing which laboratory exercises to eliminate. Three of the eight laboratory exercises performed in the Spring 2010 semester were removed from the course: the Heat Recovery Lab, the Bomb Calorimeter Lab, and the Gasification Lab (briefly described in Table 1 above). The student survey response show in Fig. 2 is representative of their thoughts on these labs.

The five remaining laboratory experiments, which have been expanded due to the improvement of their operating condition, comprise a more appropriate amount of work for the one credit hour value of the course.

4.2 Changes and Additions to Course Content and Materials

Several changes designed to improve student learning outcomes have been made in the delivery of the Thermo Fluids Laboratory course. In the past, the instructor gave a brief (10-15 minute) introduction to each of the laboratory exercises and then sent the students to perform the labs. The lab report was due before the beginning of the next class period. In the new schedule, two class periods are devoted to each of the five laboratory exercises. The first class period for each lab will remain a brief introduction to the apparatus and procedure of the lab, as well as a review of the thermo-fluids theory behind the operation of the equipment. The second class period devoted to a lab will serve as a question-and-answer session for the students to discuss any difficulties that they had either with the equipment or with the analysis of the results. Both the student and instructor surveys indicated that this additional student/instructor interaction was desirable and would lead to improved student understanding of the relevant thermo-fluids concepts. In addition the handouts that accompany each laboratory exercise have been updated to reflect the current operational condition of the equipment.

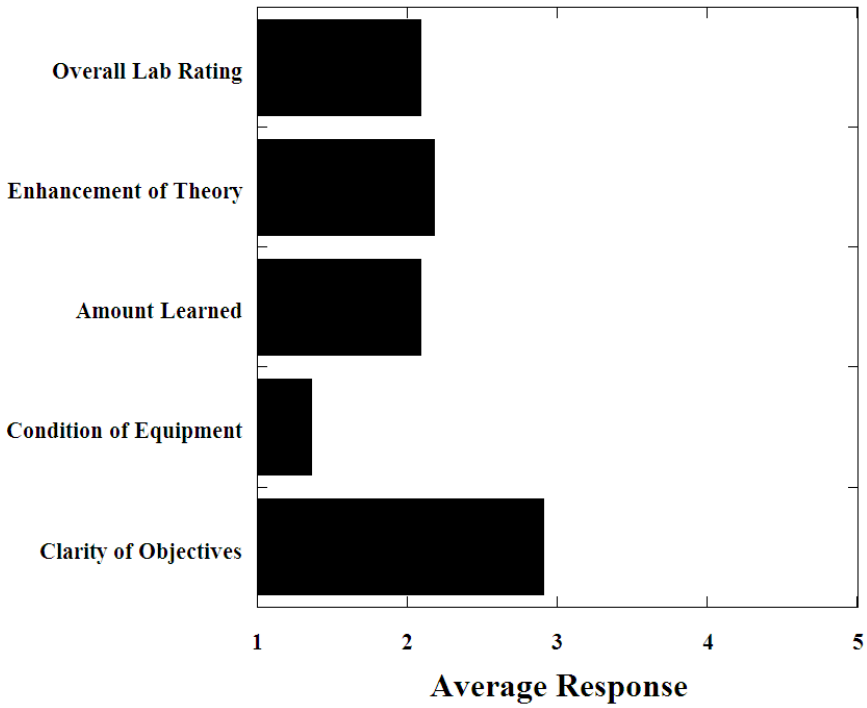

Fig. 2. Average response from student survey for the Heat Recovery Wheel Lab. Scale: 1 – Poor, 2 – Below Average, 3 – Average, 4 – Good, 5 – Excellent

The course materials (lecture notes, lab handouts, etc.) that were most recently used had been passed down through numerous instructors; these materials were edited to clarify the theoretical concepts governing the operation of the equipment and clarifying the objectives of each of the laboratory exercises, as well as to provide a consistent format to the material presented to the students.

Two topics relevant to laboratory experimentation have been added to the schedule as lecture topics. This course has not in the past contained any lecture topics separate from the introduction of the laboratory exercises. However, the two topics that have been added here (analysis of experimental uncertainty and design of experiments) are essential skills for researchers and engineers who must conceive and design experiments in their professional practice.

In previous semesters, the sole method used to assess the progress of the students was the grading of group laboratory reports. To improve the assessment of students and provide earlier and more feedback online pre-lab quizzes were integrated into the course. . These quizzes presented multiple-choice and brief calculation questions concerning the lab to be performed in the next class period. The intent of these quizzes was to encourage the students to read the laboratory handouts containing theory, experimental setup, and procedures, before coming to class. This should alert the students to background theory from previous thermo-fluids courses that they may need to review. The students then had the opportunity to review the material on their own or prepare questions to ask in the introductory discussion of the lab with the instructor. Additionally, student performance on these pre-lab quizzes may be used in the future to help assess the effects of further course modifications.

4.3 Summary of Before/After Lab Assessments

At the close of the Fall 2010 semester, students who had taken the revised laboratory course were invited to respond to an identical survey that the previous semester's students had taken (with questions about the three lab experiments that were eliminated from the course omitted from the survey). The survey results of the Fall 2010 semester were compared with the results of the previous semester. The students' responses indicate significant improvements in their comprehension of theory, clarity of objectives, condition of equipment, and overall laboratory rating. An example of this is shown in the student survey results for the questions regarding the Air Compressor Lab are shown in Fig. 3.

The student surveys also included questions about how the students felt the course as a whole had contributed to their development of important skills which are directly related to the desired student learning outcomes of the course. The results from the group who took the course after the changes had been made showed that their assessment of the courses contribution to their learning was significantly higher than for those who took the course before the changes were implemented. The results of the portion of the student surveys that asked about the course as a whole are shown in Fig. 4.

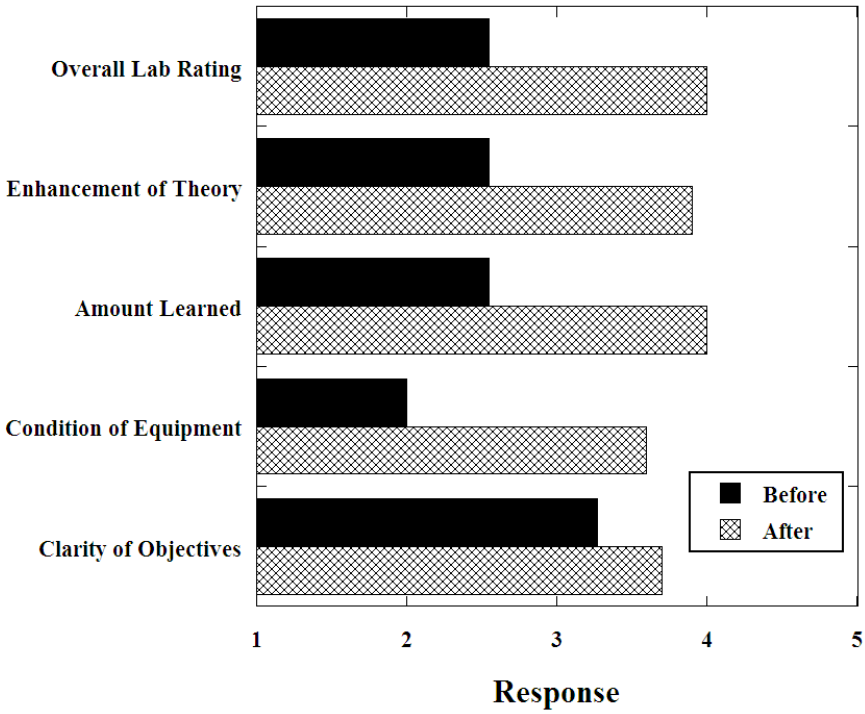

Fig. 3. Average response from before/after student surveys for the Air Compressor Lab. Scale: 1 – Poor, 2 – Below Average, 3 – Average, 4 – Good, 5 – Excellent

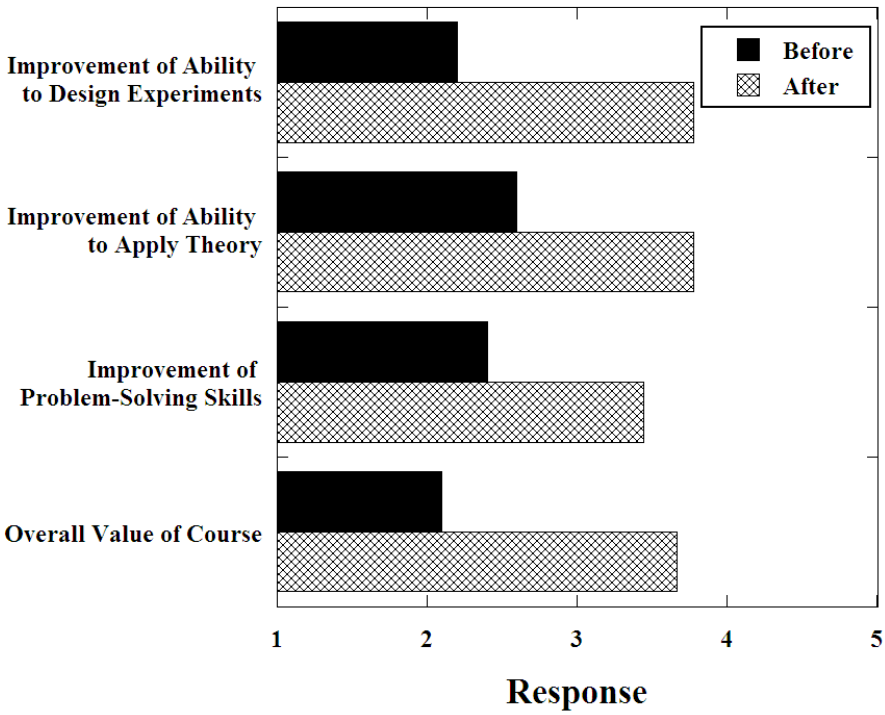

Fig. 4. Average response from before/after student surveys for the Thermo Fluids Lab course. Scale: 1 – Poor, 2 – Below Average, 3 – Average, 4 – Good, 5 – Excellent

Since a new instructor (one of the authors of this paper) was teaching the course for the first time in the Fall 2010 semester, some other useful means of assessment, such as a comparison of lab report quality before and after implementation of the changes, were not available. However, as modifications continue to be made to the course, these methods will provide important indications of the effectiveness of changes.

5. Conclusions

This project sought to improve the student learning outcomes and student success in the Thermo Fluids Laboratory course at South Dakota State University. A survey of former students and instructors of the course helped to identify the areas of weakness and directed our improvement efforts. The laboratory equipment was inspected and repaired as needed. This resulted in a greater range of possible experiments that could be performed. A state-of-the-art data acquisition system was purchased to allow the students of this course experience using equipment of the type they will see in their professional practice. The elimination of some of the labs and rearranging of the schedule allowed two class periods to be dedicated to each of the laboratory exercises, allowing more in-depth investigation of the operation of the equipment and greater student/instructor interaction. Pre-lab quizzes have been added to provide more opportunities to assess student learning throughout the course.

The results of the before and after student surveys show that the students of the changed course feel that the course better meets their needs of improving their skills in the areas of designing experiments, applying theory learning in lecture courses to real systems, and problem solving than did those students who took the course before the changes were implemented. The overall perceived value of the course to the overall education of the students was much improved as well.

Acknowledgments

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