AC 2007-2198: LABORATORY IMPROVEMENT: A STUDENT PROJECT TO DEVELOP INITIATIVE AND INNOVATION AS A PERMANENT STATE OF MIND

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Laboratory Improvement: A Student Project to Develop Initiative and Innovation as a Permanent State of Mind

Abstract

This work presents a student project for an undergraduate mechanical engineering laboratory, exemplified here by the Thermal Sciences Lab. In this project, as part of the final grade, each student lab group (typically a group of four) had to conceive and offer improvements or better ways to do a specific laboratory. There were no other imposed restrictions, meaning that the improvements could be in any area, such as hardware, software, work procedure, technical presentation, etc.

By having the project running in parallel with the labs several objectives were attained. The first objective was related to the fact that our department recognizes that, especially in today's global-scale competitive market, seeking innovation and spotting opportunities is essential for engineers; therefore students should be exposed as much as possible to the ideas of continuous innovation and product or process improvement. Second, being a group project, students were exposed to the practical aspects and important advantages of collaboration and brainstorming. Third, due to the latest innovations in technology and education, laboratory based work is always in need of enhancement; students engaged in performing lab work are well positioned to understand the possible shortcomings, and thus propose improvements; each student, according to his or her own ideas and experience (such as experience gained during the coop program), should be able to have a contribution, ranging from very small to significant, to at least one of the labs he/she was exposed. Lastly, best solutions can be followed by senior design projects in which the proposed improvements are further developed and implemented in the laboratory.

This paper shows how the project was organized in our department, and also presents some of the most significant results obtained during its first-year implementation. Based on the positive results obtained, it was used again in the subsequent semester, and most likely will be used in the future.

Introduction

Numerous studies have indicated that, in the global nature of today's economy, and even more in the economic environment of the years to come, the students we teach today will have to compete or work with engineers from around the world. In this context education becomes even more important. For example, a recent report on the future of higher education[1] shows that "in tomorrow's world a nation's wealth will derive from its capacity to educate, attract, and retain citizens who are able to work smarter and learn faster"; "ninety percent of the fastest-growing jobs … will require some postsecondary education".

The quality of higher education is therefore extremely important. Many companies, such as General Electric and Intel, are well aware that globalization directly implies "finding and attracting the unlimited pool of intellectual capital - the very best people - from all around the globe"[2]. Higher education must promote the principles of "initiative, independence, resourcefulness, and collaboration" [3]. Today's students must develop key 21st century skills such as familiarity with information and communication technology, problem solving, critical thinking and collaboration[4], as well as being ready to follow a professional path with multiple careers[5].

For a long time American higher education has been recognized as a global leader. The same report[1] recognizes that "American institutions of higher education have become a magnet for attracting people of talent and ambition from throughout the world". However, many sources, including our government, consider that the American lead is threatened. Michael E. Porter, professor at Harvard Business School mentioned in a recent interview that nowhere is the U.S. lead more threatened than in education, particularly in the areas of science, math and engineering. "It's a weakness. We're lagging behind." The report of the Commission on the Future of Higher Education[1] mentions that today our universities are not preparing the workforce needed to compete in a global economy. Employers often complain that "new graduates they hire are not prepared to work, lacking the critical thinking, writing and problem-solving skills needed in today's workplaces." Even sources not agreeing with the statement that higher education is in a crisis recognize that the most valuable strengths of our system, "initiative, independence, resourcefulness and collaboration" must be continuously cultivated[3].

The Department of Mechanical, Industrial, and Manufacturing Engineering (MIME) from the University of Toledo, after numerous talks with the alumni and with representatives of companies that hire many of its graduates, reached a similar conclusion, namely that students need to show more initiative, creative thinking, and problem solving skills. As a consequence, faculty members have been asked to take action in this direction. The present work addresses this issue. In particular laboratories, by their practical nature and by having the students organized in relatively small groups, are among the best positioned academic tools to help reach this objective.

There are numerous strategies to help encourage initiative and creativity in students, and probably the best way is to apply these strategies in different classes, as well as outside the class. For example, in Vibrations Laboratory offered the MIME department, the strategy implemented was to change the laboratory from a subject-based approach to a problem solving approach[6]. However, this change may not be easy to implement in all other laboratories due to their specific nature. Some other methods to encourage initiative are to advise students to get involved (registering for small classes is a good way to facilitate this)[7], or changing the labs from recitation and following instructions to an approach based on studio learning[5]. The present work intends to add a new way to develop these desirable qualities in our students.

Project content

The Thermal Sciences Laboratory within the MIME department is comprised of 12 different lab setups covering different subjects from Fluid Mechanics (friction in pipe flows, flow measurements, buoyancy, etc), Thermodynamics (Brayton, Rankine, and Refrigeration cycles), and Heat Transfer (cooling fins, heat exchangers, forced convection, etc.). Some of these laboratory experiences have been recently updated (such as the Rankine cycle, the Brayton jet engine cycle, and convection), while others have been intentionally kept as simple as possible in order to promote a better understanding of the basic physical concepts.

The newly added laboratory project discussed here requires each team of students to propose one or more ways to improve a laboratory work experience of their choice. The improvements could be in any section of the lab; they had to be relatively inexpensive to implement or, if a more significant investment was necessary, it had to be detailed and justified. Students were made aware that just pointing out necessary repairs/maintenance was not considered a valid improvement proposal, but coming up with ways to prevent such repairs or reduce maintenance for the future could be.

The assignment sheet handed to the students included some directions related to the structure of the report: Title page, Abstract, Introduction, Description of the proposed changes (which should include not only the envisioned improvements, but also a cost estimate and possible shortcomings), Conclusions, and an Appendix to provide information about the meetings they held to develop the proposed ideas.

In addition, the assignment sheet included some examples of possible improvements in diverse areas. The main reason for including these examples was to make the students aware about the many possible directions in which they could propose an improvement. Another reason was to introduce them to the types of outcomes expected from their projects, while not spending additional time in class to accomplish this. The total time spent in class discussing the project was less than 30 minutes. The examples provided were divided into several categories.

Hardware changes

- Propose a new setup and procedure to study the same physics with the setup already in place, but which would help the students better understand the physics by performing a different experiment.
- Propose a new data reading system to improve the accuracy of the aquired data, or the ease of data reading, and/or to read supplementary data which in turn would add new components to the experiment.
- Propose a new setup to complement the one already present by adding one or more facets to the same physical phenomenon under study.
- Using roughly the same experimental setup, but adding more operations and measurements, propose how other thermal sciences phenomena can be studied in addition to the ones already being studied (such as by using a setup developed for the study of the Rankine cycle, to also study the performance of a heat exchanger which is part of the setup).
- Change the setup to eliminate existent perceived flaws.

Procedure changes

- Using the same assemble or making only simple changes to it, propose a new work procedure for the experiment and acquiring data, thus allowing the students to better understand the physics presented.
- Change the lab handout/presentation such that it would make the procedure, data reading, or the physics involved significantly clearer. If

the handout was considered confusing, propose a version of the handout (including figures, equations, procedure description, etc.) that in the student's opinion would better communicate the material under study.

Software changes

- Propose a new way to analyze experimental data by using a mathematical/data analysis software package.
- Use modern software packages for fluid flows and heat transfer to compute numerical results and compare them to the idealized model and to the experimental values. This comparison could reveal the impact on the solution accuracy of some simplifications made to obtain closed mathematical solutions.

Because the Thermal Sciences Laboratory has a large diversity of arrangements and themes, with various degrees of difficulty, it was assumed that each team should be able to find some ways to contribute to this project. At the same time it was recognized that not all groups of students will be able to have contributions significant enough to get the maximum score for the project. For this reason, and also because of the novelty of this project, it was decided that this should be considered an extra-credit assignment, at least for the first few semesters.

Results and Discussion

During the first semester that this project was initiated (Fall 2006), the results were encouraging. The students were introduced to the project only after they had gone through a few laboratory experiences because the project outlines were not finished by the first day of classes. Many students were very interested in the project and submitted good quality reports. The instructor was very pleased to see that. While not all reports were detailed enough to meet the requirements, they all contained original ideas of improvement.

Some outcomes of the project are as follows.

a) Some of the proposed changes were inspired from the examples provided in the project assignment. However, even in these cases, the students still provided original perspectives. For example, in the handout it was indicated that one possible improvement for the refrigeration cycle would be to read the temperatures using a computer data acquisition system (as opposed to the manual reading and recording which is currently used). While one group of students used the same general idea, they also pointed out both advantages and disadvantages of this method, which were not included in the handout. For example, they indicated that the cost involved could be reduced by using a low grade computer that was current university property. They also recognized that a setup which uses exclusively a computer data acquisition system could, in case of improper operation or technical difficulties, make the lab inoperative; this is not the case with the present setup that uses analog instruments because, even for the case of one instrument malfunctioning, the setup would still be usable.
b) All projects had at least some general estimation of the cost involved to implement the proposed changes. However, some were more detailed than others. For example one

project included, together with the technical data, a price quote from the manufacturer for the proposed instruments (an infrared thermometer and a thermocouple data logger).

c) About one third of the projects explicitly detailed some of the possible shortcomings of the proposed solution. Even though this was a requirement stated in the assignment sheet, it was not a surprise that the students did not concentrate on this aspect. However, even when not explicitly stated, it was clear that in most cases they implicitly considered aspects such as cost vs. benefit. For example, in the case mentioned above, they concluded that both setups should be used for the benefit of comparing the accuracy of different temperature measurement methods.
d) Most solutions proposed simple changes directed towards a "cleaner" setup. Examples are: better, more detailed, labeling of the components of the setup, use of plastic manometer tubes instead of repairing current glass tubes, use of larger valves to allow for faster fluid drainage, use of a simple device to reduce the turbulence and therefore improve the accuracy of reading the level of the water in a tank, etc. Such changes can be relatively easy and inexpensive to implement. By providing a smoother, more straightforward environment, the students considered that changes of this nature could improve the overall experience in the lab. This was a very valuable conclusion for the instructor and lab technician because it represented some of the students' opinions, which may not be found in any other context, such as course evaluations.
e) Some students proposed more than one solution for the same problem. For example, in the refrigeration cycle setup one temperature measurement dial was malfunctioning. Because of it, two projects proposed alternate ways of measuring the temperatures, and one of them even proposed two different methods. This group compared the accuracy of the two methods and the cost involved. Their conclusion was that a "well designed experiment requires different methods of data collection to compare to the theoretical or ideal calculations" and proposed the parallel use of both methods.
f) A few proposed changes may not be considered positive from the point of view of the instructor. Most projects seemed to favor changes in which human contact with the experiment would be eliminated. The justification behind this approach was that one of the largest sources of errors, human error, would be significantly reduced or even eliminated. This approach may be inevitable in some applications, such as the jet engine laboratory, or the Rankine cycler, where measuring temperatures and/or pressures directly would be challenging or even unsafe (both these two setups have computer-based DAQs). However, from an educational point of view, students in the laboratory should be encouraged to develop an intuitive feel of the physics involved. Therefore the elimination of any direct physical contact with the experiment is in general not desirable. The fact that many students did not consider this aspect was to be expected.
g) Students from within each group actually worked together to do the project; they had to show what percentage of the project was done by each, and in all cases they indicated equal participation.

Five weeks into the second semester, students were given an anonymous survey to gauge their opinion about this project. They were asked to indicate the degree of agreement (with 1 = strongly agree, 2 = agree, 3= neutral, 4 = disagree, and 5 = strongly disagree) for a number of 14 statements. Some of the conclusions that are most pertinent to this paper are shown in Table 1.

Table 1 – Survey results

#	Statement	Average degree of agreement
1	This project makes me look at the lab experiments and setups with a critical eye.	1.8
2	When this project will be finished I expect that my team will propose at least one original, viable improvement.	2.0
3	This project demonstrates that many things can be improved from an engineering point of view.	2.0
4	Students should not be asked to propose lab improvements.	3.8
5	The project illustrates teamwork values.	2.0
6	I consider this design project to be an excellent experience.	2.2

Probably the most important conclusion is that the students showed the highest degree of agreement for the first statement, indicating that the main objective of this project, i.e. instilling a new state of mind (at least during this class), was attained. This result is reinforced by the good agreement with the third statement. As shown by the second statement their optimism was high. The second objective of this project was to encourage teamwork and brainstorming, which are especially important for innovation. As seen from the fifth statement, students concurred that the project exposed them to teamwork values. Finally, as illustrated by the fourth statement, students had a positive view of the fact that they were asked to improve their own labs. This was the only statement in the survey where disagreement was in fact positive for the project.

As stated before, the experience of the first time implementation of this project was positive. At the same time this experience provided some insight on potential improvements for the next semester, as follows.

a. Reduce the number of valid examples provided to the students in the project assignment; many of the examples provided, some of which were actual proposals made by the instructors, should in the future be replaced by ideas that have already been implemented in the past. This way, students will be more likely to come up with their own, original proposals.
b. Inform the students about the project in the first day of class (in the syllabus). As mentioned before, the different approach used in the first semester was not intentional, but rather imposed by circumstances. By having the class know about the project even before starting the first actual lab, it would more likely encourage the student to look critically at every lab while working on it. The belief is that this attitude will then be more likely to persist in other laboratories and classes, as well as in their future professional activities.

c. Organize one or two classes in the form of project presentations and discussions. The fact that their colleagues will be able to see and appreciate their work represents an additional stimulant for the students to intensify their effort and come up with original and valuable ideas. Also, the experience of presenting their proposals in a persuasive way to a public would be a valuable lesson. Finding class time to implement this would be challenging, but considering the potential benefits it may be valuable.
d. Make the opinion of the rest of the class count in the project grade. For example, similar to a Thermodynamics class project[8], the class could vote to select the best presentations, and these votes can then be used as part of the grade.
e. Include a feedback evaluation form at the end of the project, to better understand the students' opinions about it and help improve their experience in the future.

Conclusions

This work proposed a new way to encourage our students to have more initiative, seek innovation, and to collaborate with their peers, by including an additional project to a laboratory. This project ran in parallel to the normal laboratory experiences and asked the students to conceive and present improvements or better ways to do a specific laboratory. This additional project did not interfere with the existing list of laboratories, and therefore it can be implemented without difficulty in different classes.

After the first semester when this project was introduced, the experience was positive as shown by the quality of the reports and by the informal feedback the instructor had from the students. All project reports contained original ideas and perspectives, and also served as a detailed feedback regarding the students' experience in the lab. As expected, the majority of the students were probably not professionally mature enough to propose viable new experiments. However, the main purpose of this project was not to actually improve the labs, but to expose them to innovation, brainstorming, and teamwork, and thus help them develop the necessary professional maturity. Some of the more representative ideas were shown. A number of possible improvements to the project were also proposed.

Taking into account these positive results obtained during the first semester, the project will be implemented with some improvements in the following terms.

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