AC 2009-2081: A THREE-WAY APPROACH TO INVESTIGATING STUDENTS' LEARNING STYLES IN AN ENGINEERING LABORATORY

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A Three-Way Approach to Investigating Student Learning Styles in an Engineering Laboratory

Abstract

This paper presents the approach taken in the Experimental Methods in the Thermal Sciences Laboratory offered by the Mechanical Engineering Department from Northern Arizona University to investigate laboratory-specific student learning styles. To support this approach, the laboratory was reorganized to include three teaching modules: a subject-based learning (SBL) module, a problem-based learning (PBL) module, and a hybrid module incorporating aspects of both the SBL and PBL approaches. In addition, a web-based learning interface was developed and implemented to support two out of the three modules, the hybrid and the problem-based modules. The purpose of this interface was to expose the students to the theory associated with the experiment, the experimental procedure, and, for a selected number of experiments, to a video of the experiment. Providing different levels of support for the experiments, together with different visual material, allowed us to evaluate which channels of communication were most efficient in this context. An additional component of the new format of the laboratory consisted of more hands-on opportunities being created for the students. Accordingly, in the problem-based module, the students were required to design and build a setup that allowed them to investigate experimentally a theoretical problem of their choice (upon approval by the lab instructor). For these experiments, the students were required to develop the laboratory procedure and the experiment handout such that a third party would be able to perform the experiment without guidance. A set of measures was designed and implemented for each learning module. An assessment of student learning and development over time was performed using these measures. The results of assessment are presented and inferences on which learning style was preferred by the analyzed sample are made.

Introduction

This paper presents a three-way approach taken in ME 495 - Experimental Methods in the Thermal Sciences Laboratory offered by the Mechanical Engineering Department of Northern Arizona University to investigate laboratory-specific student learning styles. This work was motivated by students' feedback from previous semesters regarding their overall learning experience in the course and the general structure of the laboratory. Analysis of students' feedback, corroborated with faculty colleagues' experiences in similar courses, led to the conclusion that the subject-based learning approach was not preparing students to solve real-life problems and new/different methodologies must be implemented in this course. This conclusion is supported by current research studies.

The need for new methods in engineering education was emphasized in a recent article[1]. The integration of learning tools, learning activities, and learning evaluation of the course were counted as major components of effective teaching. The authors showed through case studies the effectiveness of new methods in improving the teaching in different engineering disciplines. They concluded that by a proper combination of the major components mentioned above one can improve students' learning. Prior to this study, faculty in the College of Engineering at the Ohio State University redeveloped the freshman engineering classes into a combined course with hands-on laboratory elements[2]. Teamwork, project management, report writing, and oral presentations were the main parts of this program.

Another recent study[3], focused on the classroom-based pedagogy of engagement, recognized active and collaborative learning as better ways for students to learn by being intensely involved in the educational process. These learning methods can further be implemented by encouraging students to apply their knowledge in many situations. The study attempts to highlight the superiority of problem-based learning over subject-based learning by contrasting the two approaches in Figure 1. Problem based learning (PBL) relies on the idea that posing the problem before learning tends to motivate students. The problem drives learning on a 'need to know' basis. PBL helps students understand why they are learning the new knowledge. Furthermore, learning in the context of the need-to-solve-a-problem tends to store the knowledge in memory patterns that facilitate later recall for solving problems. Subject based learning (SBL) relies on the premise that the students know very little. Accordingly, new information is laid out in preselected sequences. These sequences are in sync with what the teacher or the author of the text consider that the students need to know. In the SBL approach, the text is a must read resource to ensure that no information potentially useful for solving a certain problem has been omitted during lectures. The authors highlight the following attributes of the problem-based learning method: (1) Learning is student-centered; (2) Learning occurs in small student groups; (3) Teachers are facilitators or guides; (4) Problems are the organizing focus and stimulus for learning; (5) Problems are the vehicle for the development of clinical problem-solving skills; (6) New information is acquired through self-directed learning. More importantly, the problem-solving approach prepares students for formulating and solving problems they have never been exposed to before.

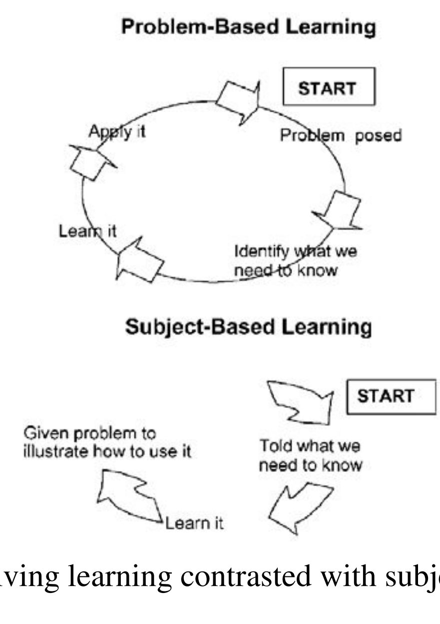

Figure 1- Problem-solving learning contrasted with subject-based learning[3].

The Mechanical Engineering Department at Virginia Polytechnic Institute and State University has been using, for several years now, a problem-solving approach to teach undergraduate laboratories[4]. At Central Connecticut State University, the problem-solving approach was applied[5] in order to develop and improve important skills in the students through laboratory experiments. The students were given limited guidance to develop a projectile device. The experience was aimed at giving students the possibility of guided practice without clearly defined boundaries. The author reported positive outcomes in terms of intra-team communications and organizing.

According to another study[6], supplementing subject-based learning with web-based preparation offers several benefits over conventional class practice. Particularly in laboratory courses, web preparation allows unlimited access to resources and provides an environment that allows students to make mistakes, facilitating learning in an active manner. Furthermore, the importance and effectiveness of using computer simulations in engineering education was studied[7]. According to this and similar studies, by using engineering software it is possible to motivate the students and to provide learning at a number of levels including cognitive and emotional. These observations encouraged us to combine in one laboratory the problem-based approach with web–based preparation and with a computer simulation of the ongoing experiment.

Method

ME 495, a senior-level laboratory course, consists of experiments in thermal sciences and fluid mechanics, including temperature and pressure measurements upon release of compressed air, conduction, boundary layer measurement, convection, and losses through pipes. Prerequisite courses for this laboratory are Fluid Mechanics, Heat Transfer and Thermodynamics I. In line with the program objectives of the department, the following list of objectives has been defined for this course. Upon successful completion of this course, students will: (1) become knowledgeable in the use of standard instrumentation for temperature and pressure measurements; (2) reinforce material studied in previous heat transfer, fluid mechanics, and thermodynamics courses; (3) improve data analysis skills, and (4) further develop laboratory and technical writing skills.

In mechanical engineering, most often the goal of a laboratory is to illustrate how the theoretical knowledge gained in foundational engineering courses can be applied to provide solutions to practical problems. Usually, this is done by setting up a flawless experiment and having students follow an experimental procedure that leads to a result that can be easily compared to certain theoretical predictions. Prior to this work, the ME 495 course was configured according to this model. In the lab portion of the course, students were required to perform a number of carefully designed experiments following a step-by-step procedure developed by the faculty and the teaching assistant running the lab. This approach, while effective when the intent was to expose students to a large number of experiments and teach them how to carefully follow rigorous procedures, was very ineffective when the goal was to teach students to be independent thinkers and problem-solvers.

Acknowledging that student learning depends on their personality and previous training, three modules/approaches were included in the redesigned laboratory in order to identify the teaching approach that would best lead to preparing students to become problem-solvers. This method, while not ideal (because it involves student exposure to three different learning styles in a short time period), was adopted because the course is offered only once a year and immediate solutions were sought to improve our students' overall laboratory experience.

The first module included three experiments that were introduced to students in the traditional format, i.e. with step-by-step instructions to be followed during the laboratory session. Students were required to read the laboratory handout prior to the lab session and refresh the theory associated with the ongoing experiment. In this module, no measure, such as quizzes, was used to assess students' readiness for the laboratory experiments.

The second module included three experiments as well. This module built on module one. In addition to providing students with a lab handout containing a step-by-step procedure for the experiment and a review of the theory associated with it, a demo of the experiment was developed for two of the three experiments and was posted on the lab web interface.

The third module consisted of three experiments and was basically a stand-alone module. In this module, as part of the *problem-based learning* approach, students experienced open-ended problems and found missing links in some experimental procedures. In the last experiment of this module, students were required to develop a new laboratory experiment on a topic of their choice together with the corresponding procedure and to report on their results. The topic for the project was selected in the sixth week of the semester and was submitted to the instructor for approval. Asking the students to choose a project topic forced them to research the subject matter of their choice and put the required experimental work in the lab context. A small budget, provided from the class fees, was allocated to each student team to purchase materials needed for the completion of the experimental setup. This provided a unique opportunity for students to experience firsthand the difficulties associated with experimental investigations that otherwise would not be apparent due to the careful design, by others, of most experiments performed during the semester. Topics accepted for the projects include: Power output measurement and evaluation for a stacked fuel cell, Drag force measurement on a ping-pong ball, Temperature monitoring in an engine exhaust manifold, Torque output measurement of a two-stroke engine, Power harvesting from environmental vibrations. For either of these experiments, the students working in teams of four, built the experimental setup, developed the experimental procedure, performed the experiment, compiled a report and delivered a presentation on their work.

A web interface was developed for all three modules. This interface had different content for each of the modules. For all modules, the objectives and theoretical background were described. In the second module, the objectives and theoretical background sections were supplemented with demos of the labs. These demos enabled students to get laboratory experience before entering the laboratory facility and were implemented knowing that nowadays students have a short attention span and a preference for visual information/communication. For the third module, the demos were substituted with quizzes that tested students' theoretical understanding of the experiments to be performed.

As part of the subject-based learning approach, for all three modules, a classroom lecture preceded each laboratory session. The lecture consisted of the introduction of experimental techniques, statistical analysis of the experimental data, and brief review of the theory pertaining to each experiment to help students refresh their knowledge on the subject. Additionally, the description and procedure of the laboratory experiment, when available, were covered during this lecture.

An emphasis was also placed throughout the laboratory on team work and development of leadership skills. Consequently, at the beginning of the semester students were asked to organize themselves into teams of four. These teams remained unchanged throughout the semester. Upon completion of a laboratory, each team was required to submit a report. A regular report contained the following sections: executive summary, introduction, methods, results, conclusions, and discussion. Each team member was responsible of one of these sections, except for the team leader who was required to submit the executive summary and the methods sections. In addition, the team leader had the responsibility to analyze each members' submission, to request a rebuttal when necessary, and then to combine all the submissions into a unified report. This process was implemented with the expectation that a reduced writing workload would increase the quality of the reports. With each new report, the students' roles and writing assignments were changed to ensure that all students had a chance to assume the leader position and to improve their writing and analysis skills by completing a different section for every report.

The questions that motivated this study were:

1. Did the ME 495 course promote growth in student learning over the course of the semester?
2. Which of the lab teaching approaches used in ME 495 helped students learn the most and why?
3. Did the ME 495 course meet students' learning expectations?

To answer these questions and to assess the overall learning experience, we used several tools to collect students' input. In addition to the traditional tools available to any instructor, i.e. quizzes, tests, laboratory reports, and project grades, we administered three self-assessment questionnaires at the beginning, middle, and end of the semester. In these questionnaires we asked the students to evaluate their level of knowledge in certain areas, before, during, and after the course. This study was performed during the fall of 2008 in the ME 495 course having an enrollment of 24 students.

Results

Multiple inputs, both qualitative and quantitative, indicated that the course promoted growth in student learning over the course of the semester. In the self-assessment questionnaire administered at the end of the semester, several students commented that overall the course was a beneficial learning experience for them:

- "*Before I took the class I wasn't sure what the course entailed. However I do know that I have learned a great deal in the course so far, many concepts have been reinforced and I believe I know more about errors and experimental design.*"
- "*I felt that the course gave a great idea of how to design and set up an experimental apparatus and then assess its flaws.*"
- "*I feel that I can now go out into the field and conduct testing and be capable of interpreting the results accordingly.*"

An item in the same questionnaire specifically asked students to what extent has the laboratory experience contributed to their knowledge, skills, and personal development. Again, students responded that the course contributed positively to their learning and development as shown by the comments below:

- *"It has strengthened my ability to analyze experimental data and report on that analysis in a technical writing aspect."*
- *"Helped with team work when writing lab with group, also helped time management finding times to meet with other group members."*
- *"I'm still not completely confident in my ability to design and do an experiment successfully, but the lab greatly improved my knowledge and skills."*

Furthermore, the exam grades indicated an improvement in student performance between the midterm exam and the final exam (see Figure 2). A *t*-test performed on the exam grades showed statistically significant improvement over the course of the semester. Both the student input and the grades supported the conclusion that students came out of this course with greater knowledge and skills than that with which they entered the course.

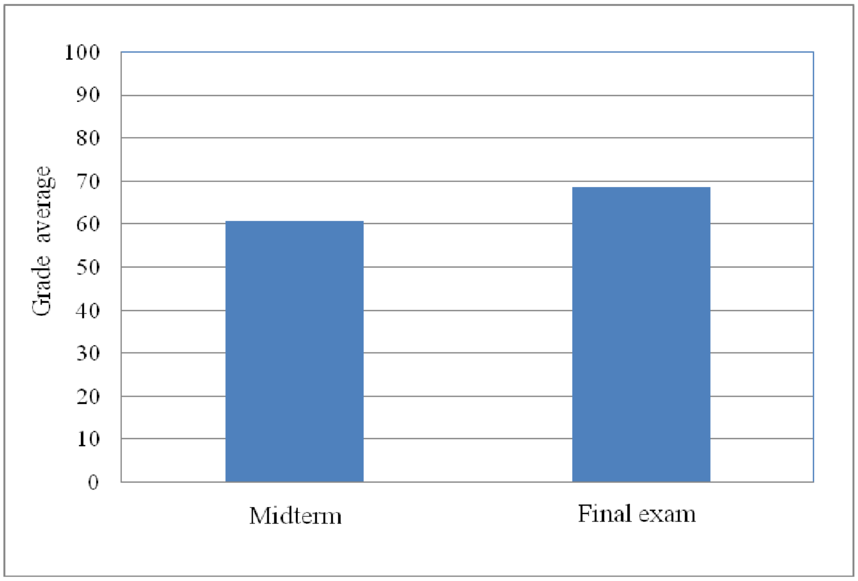

Figure 2 – Grade average on the two exams administered during the semester.

An examination of the averages on lab and project report grades, as shown in Figure 3, further illuminated student growth over time in the course and indicated an interesting evolution during each teaching approach cycle. For the first two cycles, each consisting of three labs, the students seemed to have had a difficult time adapting to the lab requirements and, correspondingly, their grades in the first report in the cycle were the lowest. However, once they became accustomed to the lab requirements in that cycle and also probably due to the feedback on their previous report, their grades increased significantly. It is unclear, though, why the grades dropped on the last report of these cycles. Interesting enough, in the third lab cycle, the pattern changed. After a very good start (see lab 7), mainly because additional help was provided for this lab, grades fell and remained constant for the last two reports. A clear explanation for this trend is difficult to give. However, it seems that the students, both individually and as a team, needed about two lab cycles before finding their "equilibrium state" late in the semester.

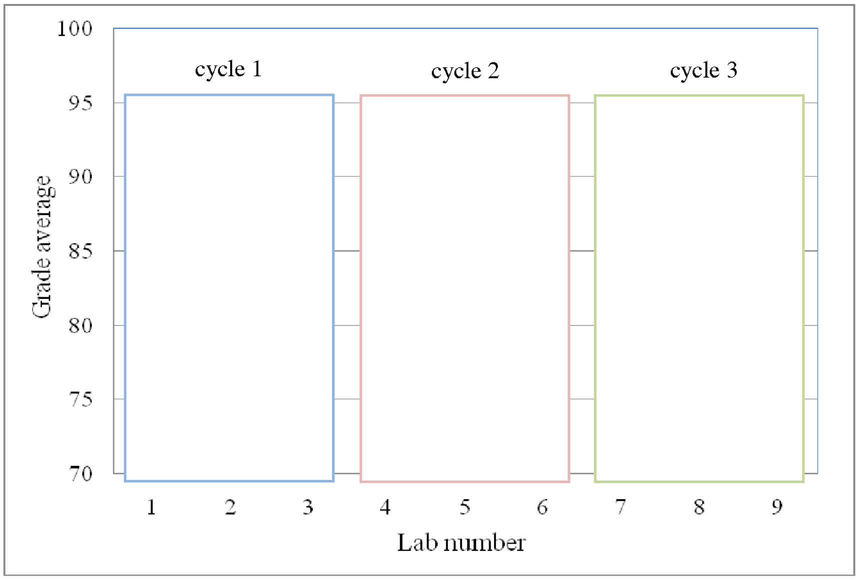

Figure 3 – Grades on lab and project reports (project is number 9).

Midway in the semester, students were administered a questionnaire in which they were asked, among other questions, which of the lab teaching approaches helped them to learn the most and why. Students' answers indicated a variety of preferences as far as teaching methods. One student commented that he favored the independent, problem-solving approach: "*The decreasing amount of direction provided in the labs require us to think about how we can conduct the experiment in order to obtain all of the data required to complete a lab report. I think this works well for me.*" Another student agreed that *"as far as the "real life" simulation, the do your own method to find a solution was very useful in teaching us how to go about doing that."* In contrast, another student responded that he favored a subject-based approach: *"A set of basic instructions helped (as opposed to "figure it out") was better because it allowed more time to perform the experiment and collect data."* Several students indicated that traditional lab approaches tended to bore them, while problem-solving approaches mobilized them better and made them more interested in the lab:

- "*The fully outlined methodologies make lab a little boring and thoughtless. Basically, some direction with outlined deliverables were the best.*"
- *"The vague but somewhat outlined labs were most useful. For instance, the wind tunnel lab, where we know mostly what we need to do, and more importantly, know what the deliverables are to be."*
- *"I liked most the one where you didn't give up anything but what you wanted out of the lab."*

Complementing the handed out materials for the lab with the web interface seems to have helped to some extent. One student noted that *"the video* (embedded in the web interface) *really helped save time as we were able to see how to use the equipment."* Another student observed that *"the lab approach that helped foster learning was focused on letting us, the students, do pre-lab exercises to gain a better understanding of the experiment."* However, students' feedback did not unanimously favor one approach or the other, so a definite conclusion on which approach is most beneficial for student learning cannot be drawn at this time.

At the beginning of the course, students were asked what their expectations in relation to this course were. Some students were unsure about what they were expecting to learn, while others highlighted what they would like to learn, as indicated by the following questionnaire responses:

- *"Don't quite know yet what the class will entail, but I hope to get a solid understanding of formulating and running test experiments as well as take my technical report writing skills up another level."*
- *"I don't really have any expectations but an enhancement of practical and real life experiments (rather than theory) would help me understand and be better prepared for industry."*
- *"Learn how to conduct real life experiments and know how to analyze the data correctly."*

At the end of the course, however, when students were asked if the course met their expectations, most students indicated that the course had met their expectations:

- "*It has met them, I have learned real engineering experiments and actually see myself using them in the future.*"
- "*I was able to grow as a leader, gain further understanding of statistic and lab applications.*"
- *"I feel that I can now go out into the field and conduct testing and be capable of interpreting the results accordingly. This class has went above and beyond what I was expecting."*

These open-ended comments were supported by students' responses on the quantitative portion of the questionnaire. When students were asked at the end of the course whether the course increased their knowledge and experience in designing and conducting experiments, out of 24 students, 12 answered "strongly agree", 9 answered "agree", and 1 student answered "strongly disagree". From these answers we concluded that overall students' expectations were met.

Conclusions

The work presented in this paper was motivated by the fact that different students have different learning styles and that one teaching method doesn't fit all personalities. In an attempt to identify what teaching method promotes most growth in student learning, a laboratory course traditionally taught on a subject-based approach, was modified and taught to progressively transition from a subject-based approach to a problem-solving approach over the course of a semester. In addition to using traditional metrics (i.e. grades on lab reports, exams and quizzes) to evaluate students' growth, a number of questionnaires were administered during the semester. The quantitative metrics as well as students' feedback indicated overall student growth during the semester. Students reported that changing teaching approaches kept them motivated and engaged in the activities associated with the lab. These findings entice the authors to consider the three-way approach in future semesters and to refine it by building on its strengths.

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