AC 2012-5048: REDESIGNING BME INSTRUCTIONAL LAB CURRICULA USING PROBLEM-BASED LEARNING AND BACKWARD DESIGN

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Problem-Based Learning in a BME Instructional Lab: Lessons Learned

Abstract

The Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University has implemented a problem-based learning approach in the systems physiology instructional lab. Traditional lab coursework was originally redesigned and tested as part of a comparison experiment in the spring of 2007. In subsequent years, the lessons learned with the first cohort were enacted in curriculum. This paper reports on comparisons of data from the 2011 cohort with that of the original 2007 cohorts—experimental and control.

In our original 2007 comparison experiment, students in the problem-based learning section reported having less confidence in the lab environment and with techniques than the control group that participated in the traditional curriculum. This was in contrast to their actual mastery of the skills practiced in this course that was better for the pbl experimental group than for the traditional control cohort. Interventions in the form of a lab manual and focused facilitation were put into place. Data from this follow-up study (2011) indicate that confidence in the lab setting and with techniques was, indeed, improved at a statistically significant level without sacrificing student perceptions of independence.

Theoretical Framework

During the spring semester of 2007, The Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University conducted a comparison study of an alternative pedagogical approach to traditional instructional labs. Using backward design (McTighe and Thomas, 2003) in which curriculum change is developed around identified and defined "big ideas" that give rise to essential questions and authentic performances, the Biomedical Engineering (BME) systems physiology lab instruction was reverse-engineered to reflect relevant skills-- that is, a focus on the practices, and experiences valued by the BME practitioners as well as employers and colleagues in the professional domain. The interdisciplinary nature of biomedical engineering indicates a need to structure the accepted practices of the typical biology lab to reflect the problem solving nature of engineering. Thus, we grounded our "big idea" in the objectives developed by a 2002 colloquy commissioned by ABET through the Sloan Foundation. The fifty engineering educators identified thirteen fundamental objectives of engineering instructional laboratories: instrumentation, models, experiment, data analysis, design, learning from failure, creativity, psychomotor (selection, modification, and operation of appropriate engineering tools), safety, communication, teamwork, ethics, and sensory awareness (using the human senses to gather information and make judgments when formulating conclusions about real-world problems) (Feisel & Rosa, 2005). These instructional lab objectives as consistent with the ABET criteria determining that engineering graduates should be able to apply knowledge of mathematics, science, and engineering; design and conduct experiments, as well as to analyze and interpret data; identify, formulate, and solve engineering problems; understand professional and ethical responsibility; communicate effectively; develop a knowledge of contemporary issues; and use the techniques, skills, and modern engineering tools necessary of engineering practice (ABET, 1997; ABET 20012-13; Felder, 2003).

We added an overarching "bigger idea" across the thirteen objectives: relevance. We designed our lab curriculum to have relevance to biomedical *engineers* around the associated essential questions: what lab practices have meaning in the real world of the biomedical engineer? what do BME graduates need to know about the content, techniques, and practices of the lab? how will they be expected to put into practice the lessons they have learned in the lab? how are the expectations of biomedical engineering practitioners different that those of biologists? This focus on real-world application—authenticity-- is consistent with recommendations for instruction from the ABET standards (2011-12), as well as the Engineering 2020 Commission (2001) and NSF engineering workforce report (2005).

In a content analysis of forty-five papers describing authentic learning in different disciplines, Rule (2006) identified four themes. Authentic learning occurs under the following conditions: 1) real world problems that mimic field work and presentations to audiences beyond the classroom; 2) a focus on open-ended inquiry, thinking skills, and metacognition; 3) engagement in discourse and social learning within a community of learners/practitioners; and 4) empowerment through independent choices as related to the project. These principles of authentic learning form the framework for the Problem-based Learning (PBL) pedagogical model. Problem-based learning is a cognitive–apprentice style approach to educational practice that places learning in the context of a complex real-world problem (Barrows, 1996; Collins et al., 1989; Kolodner et al., 2003). In PBL classrooms, students are guided by a facilitator as they work toward the solution to a problem in the real world (Barrows, 1996). This work is done in a collaborative setting consistent with the Cooperative Learning approach that promotes positive interdependence, individual accountability, face-to-face promotive interaction, appropriate use of collaborative skills, and regular self-assessment of group functioning (Felder and Brent, 2003; Johnson and Johnson, 1994). To address ABET Outcomes, Felder and Brent (2003) recommend employing PBL and Cooperative Learning pedagogical principles in engineering classrooms.

Project-based Learning (Proj-BL), which is a derivative of PBL, "promotes learning through the creation of a functional artifact that embodies the knowledge learned" (Kitts and Quinn, 2004, p. 5). Developing, designing, and building a device, product, or process affords students the opportunity to apply their engineering content knowledge, problem-solving and planning skills, implementation abilities, and self-directed learning skills (Kitts and Quinn, 2004).

The curriculum developed for the instructional lab reported here is somewhat of a hybrid. It is grounded in the principles of Problem-based Learning but also includes a Project-based Learning design-and-build element as indicated by the student-enacted protocols and labs for the techniques students conduct as physical artifacts. For this paper, we will use the lower-case designation "pbl" to denote our approach that combines elements of both PBL *and* Proj-BL.

Research Design and Methods

The purpose of this study was to determine how adjustment to the pbl curricular innovation in the instructional lab may or may not have improved student outcomes as compared with data from the pilot study, specifically regarding student perception of confidence. We used a single-subject experimental design in which students from the 2011 enactment completed a likert-scale survey instrument at the end of the course. The outcomes were compared to the data collected using the same instrument in the original 2007 experiment.

Course Design In the original 2007 pilot study, students were divided into two conditions: pbl and traditional. In the controlled experiment, a procedural lab course typical of a biology lab course, pairs of students were provided with a series of linear instructions for conducting the labs and techniques. This was compared to a pbl experimental version mapped directly to the same content. Students in this experimental section were divided into teams of four students and given a problem from the real world that they then researched to determine the best lab technique to employ and enact. They, then, planned and executed the lab with limited support from facilitators (instructor and TAs). They received no instruction about what procedures to follow. They were on their own to develop a protocol and enact it. They were given a list of available materials, more than what was needed to address the problem. They were allowed free choice in the types of assays that they could perform and were responsible for requesting the appropriate materials to conduct the lab of their choosing. For example, they could choose to use an ELISA or western blot for identification of specific proteins if they deemed either of those procedures to be relevant to the problem.

In the original experiment (Spring 2007), an end-of-term comprehension test was administered. The pbl experimental group performed better in categories of definitions, instrumentation and experimental design questions (Behravesh, et al., 2007; Newstetter, et al., 2010). An end-of-term survey was used to examine student perception, most specifically related to self-efficacy . Ironically, the pbl experimental groups scored themselves statistically lower in their level of confidence in a lab setting and in executing lab techniques, a surprising finding considering students actually performed better in the comprehension tests. Finally, an item about the facilitator confirmed the difference between sections where students in the experimental group perceived more freedom to make their own decisions, as would be expected.

Outcomes from the pilot test in 2007 were used to inform, revise, and refine subsequent iterations of the two Systems Physiology instructional lab courses over the ensuing semesters leading to what they are today (Behravesh, et al, 2007; Newstetter, et al, 2010). The goal of the focused revisions to the instructional lab course itself was to continue to provide a pbl laboratory framework while better scaffolding the tools necessary for improved confidence in the lab. Cues from research labs were used to drive these modifications; common laboratory techniques were written in a Standard Operating Procedure format and compiled into an electronic lab techniques book that students were encouraged to use. These techniques were only the initial basic lab techniques to get started in the lab setting: counting cells, total protein assay, etc. The identification of the right tool for the job was still left to the students.

Moreover, in contrast to the 2007 experiment where pbl modules were mapped to the traditional ones covering specific techniques (histology, gel electrophoresis, Western blot, cell culture, and PCR), modules of the revised lab course were aligned to the specific fundamental objectives of engineering instructional labs (Fiesel and Rosa, 2005). In teams of four, greater emphasis was placed on instrumentation, experimental design and data analysis. Students began each module with a pre-lab presentation, during which they requested materials within a budget, instrumentation required to complete module, and areas where they feel more mentorship is required. As the course was a co-requisite of the Cell Biology lecture course, students proposed projects which were limited to two mammalian cell lines. The adhesion dependent (MC3T3-E1) and suspension (HL-60) cell lines were selected based on available body of work in peerreviewed literature, ease of culture, and flexibility in the type of projects for better student engagement students.

Facilitators in the revised lab course were encouraged to actively allow students to make technical but not strategic mistakes. For example, students were required to have proper positive and negative controls in their experiments but allowed to err during a western blot as long as their controls gave them clues about where the error might have occurred. Report discussion grades were weighted heavily in the final grading to encourage a revisit of procedures and methodologies that might have resulted in errors or limitations for the module.

Participants. The instructional lab considered here is a required two-credit stand-alone course. It is associated with, but independent of, a content course- Cell and Molecular Biology- that is a pre- or co-requisite to the lab course. Prior to introduction of the pbl curriculum and during the 2007 pilot study, the two courses were conjoined with the lab, theoretically, serving as a support to the lecture, although the materials between the two elements rarely, if ever, aligned. This resulted in the separation of the two courses. In the original experiment (2007) to which we are comparing our current 2011 data, there were twelve participants in a control section (traditional lab) and twelve in the experimental (problem-based) section.

Forty-seven students participated in the 2011 follow-up study reported here. All subjects participated in the revised pbl course, there was no control group as the traditional lab course no longer exists. Participants signed IRB approved consent forms. Sixty-four percent of the participants were male, 36% female. Sixty-two percent will graduate in May 2012, 14% graduated in Fall 2011, another 14% will graduate in Fall 2012 with the remainder graduating the following spring. Eighty-four percent were US citizens with 16% foreign nationals. One-third of the participants plan to attend medical school with the others scattered primarily across industry and graduate school, with some overlap between the two.

Survey. The survey consisted of multiple-choice and open-ended prompts. For this report, we considered only the quantitative data gathered on the likert-scale portion of the survey. The 5-point response options ranged from *strongly disagree* to *strongly agree* with *not applicable* offered as an additional option.

There were three sections to the self-report exit survey. The first section consisted of 13 prompts that focused on the students' perceptions of their own development during this course, for example (collapsed for simplification): *This course has helped me develop in the following areas: identifying critical problem features and attack strategies, developing provisional hypotheses and models, working as team member and leader, conducting self-directed inquiry, executing lab techniques, writing lab reports and presenting oral presentations, determining the best procedure for solving problems, feeling confident in a lab setting and with the equipment.*

The second section of the seven items pertained to teamwork. Two prompts typical of this section were: *I feel that my group members listen to me when I present information. My group has learned to function well while challenging each other intellectually.*

The third section consisted of eight prompts related to the facilitation, specifically defined as the course instructor and teaching assistants (TAs). Again, for the purpose of simplification, we have collapsed the prompts into one statement: *The facilitators guided and intervened when* *necessary to keep group on track, encouraged the use of a variety of resources, listened and responded well to student concerns and problems, gave the group the freedom to make its own decisions, provided sufficient feedback to group members.* The eighth prompt in this section referred to the students' perception of whether the problem statements were appropriately mapped to the technique to be practiced.

Results

Student perception was assessed using a similar end-of-term survey as used in the spring 2007 semester. A contingency table was constructed and a Chi-Square likelihood ratio test was performed between groups where a P-value <0.1 was considered to be statistically significant.

47 students completed the final student perception survey, used as the main metric for this study. Questions resulting in a statistical difference compared to either control or experimental sections in 2007 are shown in figures 1 and 2.

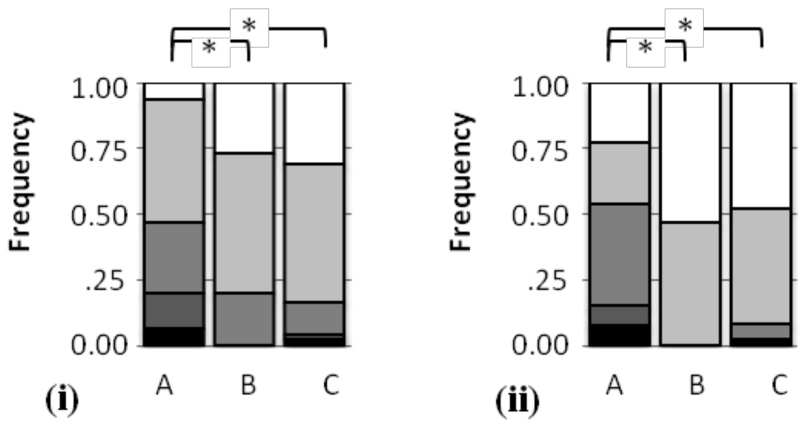

Fig 1. Final survey examining student perception of course structure in (i) allowing students to conduct self-directed inquiry and (ii) facilitator's ability to allow team to make their own decision, where A, B, and C, and the control, experimental, and revised groups, respectively. The frequency of responses is shown as grayscale bars on a 5 point Likert scale, where ''strongly agree'' corresponds to white and strongly disagree corresponds to black bars. The asterisk (*) represents a significant difference between indicated groups (p<0.1).

As might be expected in a problem-based setting, students perceived their facilitator to have given them the opportunity to make their own decisions, i.e., independence. Understandably, this is an improvement to the 2007 control group that was given a top-down managed procedure (read: recipe) to follow. It is similar to the 2007 experimental section that, like the 2011 cohort, was also given a free rein. Similarly, students in the current section perceived to develop in conducting self -directed inquiry better than the control section from 2007. When compared to the control section, there was an improvement in student development in execution of lab techniques and confidence in a lab setting with lab equipment.

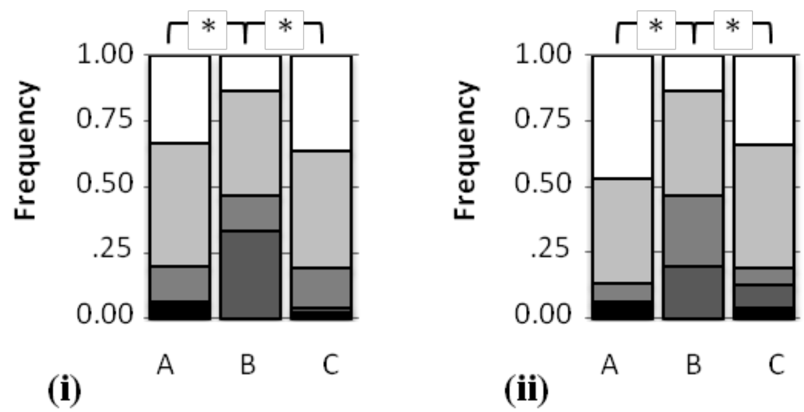

Fig 2. Final survey examining student perception of development in (i) execution of lab techniques and (ii) confidence in a lab setting with lab equipment, where A, B, and C, and the control, experimental, and revised groups, respectively. The frequency of responses is shown as grayscale bars on a 5 point Likert scale, where ''strongly agree'' corresponds to white and strongly disagree corresponds to black bars. The asterisk (*) represents a significant difference between indicated groups (p<0.1).

Conclusions

Pilot test comparison data from 2007 indicated that students from the problem-based section had a better understanding of the course content than their colleagues in the traditional lab section yet were less confident that they had "learned what they were supposed to learn" (Behravesh, et al, 2007; Newstetter, et al, 2010). In an effort to increase student confidence, a lab manual and focused facilitation were implemented. Data from this follow-up study (2011) indicate that confidence in the lab setting and with techniques was, indeed, improved at a statistically significant level. Additionally, the data show that the introduction of a lab manual and focused facilitator interaction designed to improve that confidence did not negatively impact the student's perception of independence as compared by the original experimental pbl section.

One factor that could possibly account for the original data, independent of the pbl treatment itself, relates to the psychological state of the 2007 experimental cohort. Because the students in the pbl experimental section were aware that they were participating in a pilot study to test the efficacy of a non-traditional methodology, their confidence may have been undermined by the human temptation to compare the novelty of their treatment with the "standard" being enacted in another section of the course. I call this the "grass is greener" effect. This, compounded by the guinea pig effect in which the participants are aware that something novel is being tested on them without prior evidence of its effectiveness, can create trepidation related to a sort of "what if I didn't learn what I was supposed to learn because the department was trying something new?" panic. Thus, traditional practices are imbued with some magical power due to longevity. After the initial 2007 pilot study, all sections of the instructional lab were converted to problem-based curriculum. For several years there has not been a traditionally structured instructional lab in the BME department. The pbl curriculum has become the standard for the instructional labs. Additionally, historical accounts of other methods that pre-dated our current students and the curriculum they experience are no longer an influence. Pbl in the instructional labs is all these students have ever known and enough iterations have been enacted for students to feel satisfied that we know what we're doing. While we are satisfied that the lab manual and facilitation intervention account for the increased confidence, we would be remiss if we did not acknowledge the possible role that the experimental situation itself may have had in influencing the data.

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