NSF TUES: Transforming Undergraduate Environmental Engineering Laboratories for Sustainable Engineering using the Case Studies in the Sciences Instructional Method

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Abstract

Many college laboratories follow a “cookbook” approach to instruction that has remained the same for decades. This NSF TUES Grant # DUE-1140109 is conducting educational research to evaluate the use of case study based laboratory modules that enhance the learning experience in a junior level Environmental Engineering Laboratory course. The work investigates the use of the case studies in a lab course to introduce sustainability and environmental engineering laboratory concepts to 21st century learners using a modified-flipped classroom method. A total of four case studies have been developed and implemented into the course since the grant award. Before class, the students are given a case story related to the class experiment and asked to research the topic. The in-person lab class starts with a discussion of the case and the student’s research finding. Students then conduct the lab exercise. Pre and post survey data indicated increased self-efficacy for ABET criteria skills and learning gains. Feedback from the student interviews suggested they felt the case studies methods used in the course were more engaging compared to their traditional laboratory classes they had taken during their education. The students particularly enjoyed the real world approaches and seeing how they could expect to apply course lab skills to their real jobs after graduation. This poster will summarize the cases, present pre-and post- survey data related to student learning preferences and the Accreditation Board for Engineering and Technology (ABET) learning objective criteria, and will be used as a tool to help recruit other laboratory professors who are interested in using this method.

I. Introduction

We all have experienced college level chemistry, biology or engineering laboratory courses. In these courses, laboratory instruction has consistently followed a “cookbook” approach that has remained the same for decades (i.e. a set of number ordered instructions). Students are given a set of procedures with perhaps a few pre-lab questions to answer. They complete the steps during the laboratory exercise, record the data, fill-in the answers on the laboratory worksheet, or write a report summarizing their data. Some labs may require students to follow the scientific method as they complete the procedure.

Largely, lab instruction has remained unchanged even though educators acknowledge that the new Millennial generation of student learns like no other generation before them. Educational research suggests that various teaching strategies should be implemented in the classroom to engage the millenial generation. These strategies include incorporating multimedia, having a more relaxed classroom environment, making teaching relevant to real life experiences and exploring active learning approaches [1-4]. Literature also suggests millennial learners prefer a more relaxed, informal classroom environment that allows them to actively participate in classroom discussions and helps them understand core concepts through collaborative and service learning approaches [4]. Despite what is known about Millennial learners, however, traditional laboratory courses tend to fall short of addressing effective teaching methods recommended for millennial student learning [1-4].
II. Case-studies teaching method

Step-by-step laboratories for the 21st century learner are relatively ineffective, provide limited student critical thinking, and often leaves little to no impact on student learning and content retention\textsuperscript{[5-11]}. Examples of methods to reform laboratory experiences include the use of “story” based historical cases, vignettes, dramatizations, thematic narratives, and dialogues in chemistry and physics laboratory instruction\textsuperscript{[12]}. Charles Herried et al (1994), through the National Center for Case Studies in the Sciences, has also promoted the use of cases or interactive “stories” to engage students in the sciences \textsuperscript{[9, 13-15]}. Examples of several cases for laboratory courses using the Case Studies in the Sciences pedagogy are available at the center database \textsuperscript{[16-22]}, however, few rigorous educational studies have investigated the use of the method to evaluate its effectiveness in increasing critical thinking and comprehension\textsuperscript{[7]}.

Since 2010, an educational study to evaluate the effectiveness of using case studies in an environmental laboratory course has occurred at North Carolina A&T State University. This paper presents the final cases developed for the Spring 2013 course, the case format, survey questions, and student perception of the method. In the Spring 2013 course, four case studies were used to accompany the laboratory course instruction. During the course, the students were provided with a case study related to the laboratory topic. After the pre-lab case study, the students complete the hands-on laboratory portion with the knowledge of a real-world application related to their laboratory exercise.

III. Methodology

Case Studies

The case studies were developed using the Herreid (1997) definition of the components for a good case study used in the sciences\textsuperscript{[14,15]}. Cases were created such that they were: 1) relevant to the student audience, 2) presented something for which the students could relate, or 3) were based on real-world facts, theories and principles. For each case, students could research the topic on-line, find videos, or articles to gain additional insight in the topic.

Use of Blackboard

Blackboard, a course management package, was used as the software interface to provide the students with the case 1-week prior to the lab day. Each week the students were assigned the case, which consisted of a short story to motivate their interest in the topic. Each case included a short story overview and YouTube video clips. Students were encouraged to research the topic using the recommended video clips, on-line references, and encouraged to pursue their own sources. Students were then assigned pre-lab questions related to the case and provided with the lab procedure which for they had to prepare their lab notebooks with the experiment details prior to the lab day.

Class Management

Thirty student students participated in the Spring 2013 junior level, Environmental Engineering Laboratory course. The lab course has a co-requisite Introduction to Environmental Engineering course. The lab class was two hours in duration. The students read the case, looked at the videos, and conducted research on the case prior to class. The first five minutes of the class
was used for the groups to answer pre-lab questions related to the case. The subsequent five to twenty minutes in class was used to discuss the case and how it related to the lab experiment. This time was also used to answer questions related to the lab procedure or to clarify the procedure steps. Students were required to develop hypotheses for the lab experiment and complete the lab exercise. As needed, the faculty would provide groups with guidance or discuss the case with the groups informally for the remaining lab class period. The students were paired into groups of 3 – 4 students for the lab and worked together to complete the lab report. As part of the lab report introduction and conclusions, they were required to discuss the case and how it related to the experiment or incorporate related cases into their discussion of the lab results. Group lab reports were due one week after completing the lab.

Assessment
Our hypothesis for the educational study was case studies can increase student learning and address the various learning styles represented in the course. To evaluate the hypothesis, the assessments were selected to measure three key factors, 1) Student Interest and motivation, 2) course preferences for millennial learners, and 3) increase in student efficacy related to the key concepts required by the National Accreditation Board for Engineering and Technology (ABET). Both qualitative and quantitative responses were measured. Students were evaluated using traditional metrics, such as lab reports and group presentations, which were an essential part of developing student writing skills. The students were administered pre and post surveys. The first survey consisted of twelve questions used to measure student preferences for instructional pedagogy or student preferences for teaching methods and resources used to help teach classes. This survey used a Likert scale using the rankings of Strongly disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). PRISM statistical software was used to perform the statistical analysis of survey data to calculate significance in compared data using a two-tailed t-test. The ABET survey consisted of eleven questions to measure student self-efficacy for their competencies in the Accreditation Board for Engineering and Technology (ABET) criteria areas.

Students participated in a focus group interview and a survey which included an open-ended question asking students to compare their experiences with traditional labs versus the case-based laboratory method. The interviews and open-ended responses were coded to identify common themes. Students were administered a post-course survey where an open-ended question was asked students to compare their traditional lab experience to the case studies method used in the Environmental Engineering Lab course.

IV. Results

Summary of Cases
Case 1: Narrative with a Fictional Character
Risk assessment for E-waste and hazardous waste disposal – Story of a little boy that works at E-waste Plant. Students watched three YouTube videos related to E-waste handing in the US, Ghana, and China. They review the cases as a pre-lab and answered pre-lab discussion questions. The instructor and students discussed the case and students completed the statistical analysis lab experiment during the lab period. For the lab exercise, student teams are told they are part of an advocacy group collecting exposure data for 50 workers in the e-waste plant being exposed to heavy metals. Using the deck of cards, the students generate random data that is dictated based on the lab procedure for how they count the cards. In scenario 1, the workers have a 50:50 chance of exposure. Scenario 2 the workers have a low probability of being exposed to...
heavy metals. Scenario 3 mimics workers in the plan working without personal protective equipment and being exposed to heavy metals at a high rate. Lab Skills: Statistical Analysis of data, hazardous waste, public health, risk. (Figure 1)

Case 2: Role Play - Ms. Hines and the sick 5th Grade Class

Students participate in a role play exercise where an elementary teacher calls into work to let her principal know that she is ill. The principal proceeds to inform the teacher that other students in her 5th grade class are ill too. The day before the class had a field trip to a local park that is known to have a high population of geese. The students and the teacher were exposed to contaminated water when and went to a local park.

The laboratory students had to develop a sampling plan at the park based on where the hypothetical “5th grade” class may have been during their field trip. Students collected the samples and during the laboratory session learned how to conduct field samples for water, analyze water quality parameters such as pH, dissolved oxygen, and microbial analyses. This lab consisted of 2 weeks. The first week for the case and developing a plan and the second week for sampling and analysis. Lab Skills: Biological, chemical and physical measures and to analyze for water quality. (Figure 2)

Figure 1. E-waste Case

Figure 2. Miss Hines and the sick 5th graders case

Case 3: Social Media, Printer Works

Students read the article “This is Not Farming” written by Katie Dobie (2011). This article discussed the issues surrounding Confined Animal Feeding Operations and environmental contamination. Students were asked to research the topic discussed and identify fact versus biases in the article. Lab Skills: Environmental Justice and Ethics, Identifying fact from biases,
Contamination of soil and water, EPA regulations for fecal coliform contamination in drinking water and recreational water, Quantitative measurement of bacteria.

**Case 4: Tours**

Students toured a local LEED Platinum hotel where they learn about green buildings, water conservation, and alternative energy. Students toured the roof where they learned about the solar panels and the pitch angle for the panels, xeriscaping, water recycling, and use of local and recycle materials for the hotel. For the lab experiment, students used solar panels to measure voltage from a solar cell at various tilt angles and north, south, east and west directions. Students then were asked to research the best solar panel angle for our city, explain their data, and evaluate the rationale for the solar panel angle placement used on the hotel roof. Lab Skills: Sustainable engineering, green building, alternative energy, critical thinking, data analysis.

**Qualitative Assessment**

*Open-ended Survey Questions and Interviews Response*

Students during the focus group and the open-ended survey question were asked:

“You have experienced traditional labs in other courses and case study based labs in this course. In your opinion is one method better than the other? Does it matter which method is used in a lab course? Do you prefer traditional or case-based labs? Why?”

Overall, feedback from the student interviews and the open-ended survey suggested they felt the case studies and problem-based methods used in the course were more engaging compared to their traditional laboratory classes they had taken during their education. The demographic representation for the course was twenty-two African/African-American, two Hispanic, three Caucasian/Asian, and one Native American. In the class, eight were women and twenty-two were men. Demographics for the course were considered important because educational research suggests that inquiry-based, cases, and learning experiences that present societal impact improve student learning for minority and female students\(^{[23-25]}\). In our study, both male and female students and minority and non-minority students expressed interest in the method. Significant differences were not seen in student perception of the cases based on gender or ethnic background. In response to the interview questions, the students indicated they felt they still participated in the step-by-step hands-on components, but felt the experience was more interactive. The common themes included: Relatability, Ability to apply learning outside of classroom, Interactive, Interesting, Understanding More/Increased Knowledge, Perspective, Rationale for What we are learning, Interest/Personal Investment, and Ability to Research topic. The students particularly enjoyed the real world approaches and seeing how they could expect to apply course lab skills to their real jobs after graduation.

**Quantitative Assessment**

*Instructional preferences for millennial learners*

A comparison of post survey responses using a paired t-test was performed to identify preferences between the instructional methods (Table 1). A Likert scale from Strongly disagree
(1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5) was used for the survey. The pre-survey was administered on the first day of the course and again the last day of the course. In the comparison between question 4 and question 6, students indicated a mean = 3.889 for their peers as teachers and a mean = 4.111 for informal discussions led by the professors. The means for these two methods were not significantly different (p < 0.001) thereby indicating students view each instructional method equally with only a slight preference towards the informal discussion by the professors. A comparison between peers as teachers and students leading the class discussion show students favor informal discussions with peers over peers leading the discussions (p < 0.001).  Peers as teachers compared to formal lectures by the professor showed no significant preference by the students for either instructional method (p = 0.1846). Students preferred learning from peers compared to learning individually (p = 0.015). A slight skew was seen towards formal lectures by the professor but this is attributed to prior experiences the students may have had during non-laboratory courses with the professor and her lecture style. No statistical difference was seen for student preferences between non-formal lectures by the professor and structured discussions led by the professor (p = 0.5871).

Student efficacy

A summary of selected items from the ABET self-efficacy survey are presented in Table 2. The students had a slight increase in their perception for the use of terminology, understanding professional and ethical responsibilities as an engineer, and the broad education necessary to understand the impact of engineering solutions in a global and societal context. Their perception for their ability to write a technical increased (p= 0.001). For design of experiments, student mean increased to a post-mean = 4.143 (p = 0.0001). Student competency to design experiments represented an important achievement for laboratory course outcomes. Other noteworthy differences between pre- and post- results were heightened self-efficacy among the students for engaging in life-long learning, knowledge of contemporary issues and ability to use these techniques/skills/tools necessary for engineering practice.

Table 1. Preferences between the instructional method

<table>
<thead>
<tr>
<th>N = 27</th>
<th></th>
<th></th>
<th>Mean Difference</th>
<th>p value</th>
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<tbody>
<tr>
<td></td>
<td>PRE Mean</td>
<td>POST Mean</td>
<td>(Post - Pre)</td>
<td></td>
</tr>
<tr>
<td>Q1: I learn more when we perform calculations in class</td>
<td>4.370 ± 0.742</td>
<td>4.444 ± 0.641</td>
<td>0.074</td>
<td>0.713</td>
</tr>
<tr>
<td>Q2: I enjoy working in groups</td>
<td>3.778 ± 0.993</td>
<td>3.704 ± 0.993</td>
<td>-0.074</td>
<td>0.703</td>
</tr>
<tr>
<td>Q3: I can currently communicate about environmental engineering and sustainability with classmates</td>
<td>3.778 ± 0.993</td>
<td>4.407 ± 0.797</td>
<td>0.629</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Q4: I enjoy having my peers as teachers</td>
<td>3.963 ± 0.898</td>
<td>3.889 ± 0.698</td>
<td>-0.074</td>
<td>0.646</td>
</tr>
<tr>
<td>Q5: I prefer working individually on assignments</td>
<td>3.444 ± 0.892</td>
<td>3.222 ± 1.013</td>
<td>-0.222</td>
<td>0.364</td>
</tr>
<tr>
<td>Q6: I learn better when the class discussions led by the professor (not formal lectures)</td>
<td>4.148 ± 0.818</td>
<td>4.111 ± 0.934</td>
<td>-0.037</td>
<td>0.846</td>
</tr>
</tbody>
</table>
Table 2. ABET Survey Questions for the Use of Cases to increase student learning

| Q7: I learn better when the class discussions are led by classmates | 3.259 ± 1.196 | 2.926 ± 0.917 | -0.333 | 0.257 |
| Q8: I learn better when there are structured lectures given by the professor | 4.00 ± 0.961 | 4.222 ± 0.847 | 0.222 | 0.352 |
| Q9: I learn well from independently reading course reading materials | 3.444 ± 1.086 | 3.00 ± 1.11 | -0.444 | 0.056 |
| Q10: I learn well through the use of electronic resources, primarily the Internet, to find information | 4.00 ± 0.961 | 3.889 ± 0.892 | -0.111 | 0.541 |
| Q11: I use library resources more than electronic, on-line resources | 2.296 ± 1.031 | 2.333 ± 1.14 | 0.037 | 0.876 |
| Q12: I prefer to use computers to research topics | 4.192 ± 0.801 | 4.077 ± 0.744 | -0.115 | 0.523 |

Table 2. ABET Survey Questions for the Use of Cases to increase student learning

| N = 27 | PRE Mean | POST Mean | Mean Difference (Post - Pre) | p value |
| ABET Q4: Ability to write a technical lab report (ABET Criteria B) | 3.741 ± 0.9027 | 4.407 ± 0.6939 | 0.666 | 0.001 |
| ABET Q5: Ability to understanding professional and ethical responsibility of engineering in the environment and society (ABET Criteria F) | 4.222 ± 0.6405 | 4.370 ± 0.7415 | 0.148 | 0.32 |
| ABET Q7: Ability to design and test experiments (ABET Criteria B) | 3.259 ± 0.9842 | 4.111 ± 0.698 | 0.852 | < 0.001 |
| ABET Q8: Gained the broad education necessary to understand the impact of engineering solutions in a global and societal context (ABET Criteria H) | 4.000 ± 0.6794 | 4.370 ± 0.7415 | 0.37 | < 0.001 |
| ABET Q9: Ability to recognize of the need to engage in life-long learning (ABET Criteria I) | 4.148 ± 0.7698 | 4.630 ± 0.5649 | 0.482 | 0.004 |
| ABET Q10: Knowledge of contemporary issues (ABET Criteria J) | 3.778 ± 0.698 | 4.519 ± 0.6427 | 0.741 | < 0.001 |
| ABET Q11: An ability to use these techniques, skills, and modern engineering tools necessary for engineering practice (ABET Criteria K) | 3.519 ± 0.753 | 4.444 ± 0.5774 | 0.925 | < 0.001 |
V. Conclusion

Since implementing case studies, the students have demonstrated increased student engagement in the laboratory course. Students discussed the cases outside of classes within their lab group and with other lab groups. Students shared interesting articles and information they found related to the topics with classmates. Students at our institution typically struggle with writing lab reports for rigor, content, grammar, hypothesis, and statistical analyses. As the lab course progressed, student report quality increased with marked improvement in content and critically thinking about the data. Weaker students continued to struggle with grammar and statistical analyses but also exhibited increased abilities in their critical thinking of the lab experiments and their real world application. Students with higher level writing skills excelled at the presentation of both their data and development of their reports based on the cases and their lab results.

The next phase of this work will include publishing the data collected starting in 2010 which includes n=60 student participants. In addition to the survey questions presented in this paper, the students also completed the Felder Index of Learning Styles Survey (ILSS) tool [26]. This assessment helped evaluate the learning styles to determine patterns or trends in the learning styles of engineering students. A new survey tool will be used in Spring 2014 based on a case study survey administered by Yadav et al (2010) [27]. These questions were used in his study to assess the impact of case-based instruction on conceptual understanding and their attitudes towards case studies.

VI. Acknowledgements

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VII. References


