AC 2011-985: REFORMING ENVIRONMENTAL ENGINEERING LABORATORIES FOR SUSTAINABLE ENGINEERING: INCORPORATING PROBLEM BASED LEARNING AND CASE STUDIES INTO AN ENVIRONMENTAL ENGINEERING LAB COURSE

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Reforming Environmental Engineering Laboratories for Sustainable Engineering: Incorporating Problem Based Learning and Case Studies into an Environmental Engineering Lab Course

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Abstract

An introductory Environmental Engineering course was re-designed to include new environmental laboratory modules based on Sustainability and Green Design. The goal of the course was to incorporate the skill sets taught in a traditional Environmental Engineering Laboratory into the rapidly growing area of Environmental Sustainability and Sustainable Design. This restructuring of the lab course diverged from traditional step-by-step lab instruction by using an inquiry-based “open” experiment method to enhance student learning. These changes were based on a well known meta-framework for instructional design from How People Learn (HPL)[1]. Funded by the NSF Innovations in Engineering Education (IEECI) program, this research led to the development of modules utilizing the pedagogy of both problem-based learning and case studies to teach environmental sustainability concepts. This research addresses the NSF IEECI exploratory focus to study educational approaches for how principles of sustainability can be infused into traditional courses and how educators can best provide hands-on approaches of engaging students. Student learning gains and perceptions for using inquiry based teaching were gleaned from this research. Assessment of the research consisted of pre-surveys including the on-line Learning Styles Inventory developed by Felder and a baseline student achievement learning gains (SALG) on-line assessment. At the completion of the semester, students were assessed using focus group interviews, a post-survey Assessment of Student Preferences for Teaching and Learning, and an ABET Based Questionnaire for Post-course Assessment. In keeping with the HPL concepts, the course attempted to focus on learning being driven by the knowledge, skills, attitudes, and needs of the learner. When the final focus group interviews were performed at the conclusion of the semester, students spoke on their perceived level of engagement compared to other labs they have taken. Students were also queried as to their opinion of the merit of two additional module topics for future development.

The ultimate goal of this two year research project is to develop four modules for environmental sustainability. Two modules were developed for the first year of the research with the anticipation of adding two more modules during year two. The spring 2010 modules consisted of: (1) Green Engineering Design and (2) Water reuse and recycling. The year two activities are being partially shaped by student input from the focus groups and will incorporate modules on Solid Waste Handling/Recycling and Biodegradation/ Bioremediation. The details of the two completed modules are discussed in the paper in addition to the plans for the year two modules. We also discuss the benefits, disadvantages, and the lessons learned from the first year of research for this work.

Introduction

This research was initiated to develop a method to enhance student critical thinking and analytical skills in an Environmental Engineering Laboratory course. The educational intervention entailed developing laboratory modules which use both problem-based learning and case studies to introduce lab topics. The use of problem based learning and case studies in this course first began with the PI's participating the NSF Case Studies Workshop and participation in previous research grants for use of problem based learning (PBL) for course instruction. For our work, case studies are defined as short realistic stories that provide relevant detail about an environmental problem. The case studies are used to introduce the 1-week lab topic and link the lab skills students should learn during the course to real world applications they could encounter as engineers. Problem based learning for our work will be defined as a real world problem assigned as a large project to a student team. The students are asked to identify what they know and what they need to know. Based upon their identification of what they need to know, the students conduct research for the PBL assignment and develop a solution which is presented in the group project report and presentation. By the end of the grant we will have four new environmental engineering laboratory modules that could be used for a complete semester course focusing on sustainability or used as part of a pre-existing laboratory course to enhance the laboratory curriculum.

PBL and case studies provide innovative laboratory delivery modalities to promote student learning by using active learning methods without formal lectures[2,3]. The students are provided with a problem and they discuss, research, and work as groups to solve the problem. Therefore, these methods are student focused and student-guided to help promote active instead of passive learning[4,5]. Several educational reports for undergraduate STEM education have identified the benefits of PBL and case studies to help students form a connection between the underlying abstract science concepts and their applications in everyday things [2-5].

The restructuring of the lab course to use PBL and case studies was based on a well known meta-framework core principle from the text *How People Learn* (HPL). The third core principle from HPL recommends using "a metacognitive approach to instruction that can help students learn to take control of their own learning[1]." To do this, two approaches were used. Course activities were designed to ask students to read about a real case or to investigate a larger topic through group research, tours, and lab experiments. One example of a PBL used during year 1 asked students to redesign a building on campus to use green building concepts such as alternative energy, recycled building materials and water conservation. A second example of PBL being implemented this spring 2011 asked students to build and test a point of use water treatment system that could be used by a family living in a third world county. These assignments required 2 – 5 weeks for completion. The lab activities designed to use case studies used a real world short story to introduce a sustainability topic and the students immediately completed a lab exercise related to the topic. For example, during the spring 2011 course students read and discussed a case study about E-waste recycling in China and performed a statistical analysis to evaluate the risk of exposure for workers at the E-waste facility. This teaching method could be accomplished in 1-week. Within the context of the PBL or case study teaching methods, the students learned lab skills and had hands-on experiences that directly linked course material with environmental engineering and sustainability.

Prior to our educational research funding in 2009, eight traditional lab experiments were performed during the course. These traditional laboratories addressed analyzing water samples for chemical, physical, and microbial characteristics. Experiments included measuring nitrates/nitrites, phosphates, hardness, turbidity, BOD/COD, dissolved oxygen, TDS/TSS/VS and teaching students how to quantify total coliform in water samples using membrane filtration.

Implementation

The modules used during year 1 research were developed to include green building design and water recycling/reuse modules. During year 2, the green building and water recycling modules will be improved and additional sustainability topics will include biodegradable materials and solid waste recycling modules.

Year 1 Results

During year 1, the CIEN 311 Environmental Laboratory course had an enrollment of nineteen students (17 males, 2 females). The students were junior level, Civil Engineering majors and there were no other majors enrolled in the course. The class demographics consisted of 56% minority groups (i.e. African American, African, and Hispanic). Students were asked to complete the Felder and Soloman "Index of Learning Styles Survey (ILSS assessment, http://www.ncsu.edu/felder-public/ILSpage.html). This survey instrument is a 40 question assessment instrument tool which categorizes the student's learning into several groups. These learning styles are: Active Learners versus Reflective learners, Sensing Learners versus Intuitive Learners, Visual Learners versus Verbal Learners, and Sequential Learners versus Global Learners. The PI provided a discussion about learning styles which would help the students interpret their learning style after completing the survey. Our goal for using the ILSS was to determine if there were specific learning styles or trends in the learning styles exhibited by the students in our course. Table 1 provides a definition for each of the learning styles.

Table 1. Summary of Learning Styles (http://www.engr.ncsu.edu/learningstyles)
ACTIVE LEARNERS tend to understand and learn information best by doing something active such as discussing or applying the material.
REFLECTIVE LEARNERS are learners who prefer to think about material before applying the material learned in a course.
SENSING LEARNERS prefer to learn facts and solve problems by well established methods.
INTUITIVE LEARNERS prefer to investigate possibilities and relationships. These learners are more comfortable with abstractions and mathematical formulations.
VISUAL LEARNERS learn by seeing pictures, diagrams, flow charts, films, and demonstrations.
VERBAL LEARNERS learn more by written and spoken explanations.
SEQUENTIAL LEARNERS tend to learn using linear steps in a logical order or pattern.
GLOBAL LEARNERS learn by understanding the "big picture" and then linking concepts.

The ILSS uses a ranking scale from 1 to 11 indicating a student's possible preferences or possible strengths for a particular type of learning style. This is an increasing scale for learning preferences with 1 representing the low end of the scale and 11 representing the highest level of preference for a learning style. The student's learning style preferences were evaluated individually and then averaged together to give an overall class learning style preference. The ILSS assessment for each individual student is provided in Figure 1.

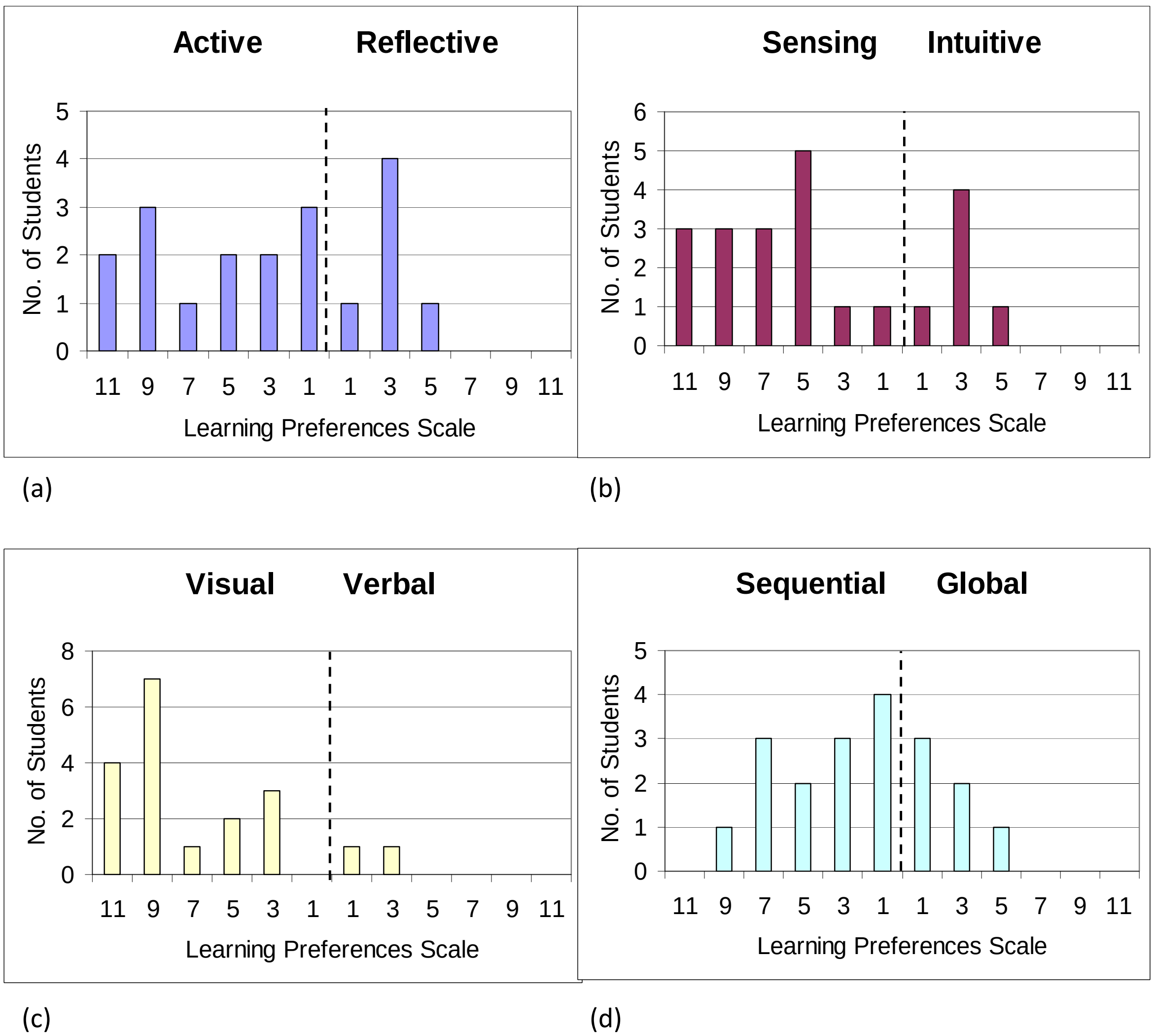

Figure 1 a – d. Learning Preferences for Students in Environmental Engineering Course and the number of students with the learning style preference: (a) Active vs. Reflective, (b) Sensing vs. Intuitive, (c) Visual vs. Verbal, and (d) Sequential vs. Global (Year 1)

The graphs show the preference level and the number of students with that preference. From the averaged data, 68.4% of the students preferred active learning and 31.6% prefer reflective learning. PBL and case studies can complement both of these learning styles. Sensing students represented 84.2% of the student population, 89.5% of the students were visual learners and 72.2% were sequential learners. Interestingly, the sequential and global learning preferences for the student's learning style was distributed in the 1 – 5 preference range as opposed to strong preferences in the 7 – 11 as seen in the other learning style groups.

Individual learning styles may be address by PBL and case study teaching methods because these methods allow the individual student to learn from the instructor, peers, and as an individual student researching and mastering material. Active learners could benefit by actively participating in lab, hands-on activities. Reflective learners can use the PBL and case studies to reflect over the problem or the framework story associated to the module activities. The research or fact gathering opportunity the students conduct while developing their environmental sustainability projects would facilitate learning for students who are sensing learners. Intuitive learners can use the case studies and PBL to investigate "what if" scenarios in their projects. Visual and verbal learners receive both types of learning styles using PBL and case studies. Sequential learners may find the case studies and PBL difficult because of their need to see linear steps in a logical order, however, real world problems do not always start in a linear or stepwise fashion. Global learners through the PBL and case studies can see the "big picture" of the module.

Student Groups

Students self-selected laboratory groups consisting of 3 – 4 team members and the laboratory course met once a week for two hours. Students worked in the groups outside of class to complete projects, reports, and presentations. At the beginning of the session, the instructor introduced the module topic using a presentation that provided an overview and schedule for the module. Each module consisted of the problem statement, a tour or site visit which demonstrated the module in a real-world application, an in-class assignment which included a class discussion, and a team project the students completed for the module. Blackboard was used to help post resources for the students and to help exchange information the students found related to the topic. Students were asked to conduct their own research in the topic area on the internet, in journal articles, and books. Lab analyses were taught after the student/professor discussions. During the discussions, the purpose was to have the students identify the environmental lab tests that were needed to analyze their samples such as measuring turbidity or microorganisms present in a water sample. Students therefore first understood "why" they needed to conduct the lab analysis and how the analysis they would learn in class directly related to their project as opposed to the professor dictating the weekly experiment. This could be considered a "reversed" method of instruction where the students understand the purpose of the experiment and how it "fits" into a real world application before learning the analysis in the lab course. After the discussions and determining the lab tests needed, the professor provided the lab training for the students and they could use their data to complete the project assignment.

Modules

Module 1: Sustainable Engineering and Green Engineering Design PBL Project (4 weeks)

The Green Engineering Design project was the first module used for the course. The module presentation initiated the background discussion with the class to help understand a basic definition of sustainability, green engineering, and the economic impact of sustainable practices. A power point presentation with photos of green buildings in the United States and third world countries was used during class to stimulate discussion with the students. During the presentation, cases studies were introduced to provide examples of real world projects which implement green building, water conservation, energy efficiency, and sustainable construction materials. After the discussion, the PBL project assignment asked students to select a building on-campus to redesign. Students were asked to consider the function of the building and the groups were provided time during class to complete a guided response assignment about their building and green building. During week 2, students went on a tour of the Proximity Hotel. The Proximity Hotel is the first LEED Platinum Hotel in Greensboro, NC. The tour at Proximity provided the opportunity for students to see the solar panels, roof design, xerscaping, recycling and re-purposing of construction material, innovative guest room designs, energy conservation, water conservation, and geothermal energy use in the hotel restaurant. Students could then use these features to help with their redesign of their building. There were no formal lab experiments developed for this module during year 1, however, there is potential with this topic to have students actively participate in the research NCA&T graduate students are conducting at the Proximity Hotel. Lab experiments for understanding solar energy, solar heating, and hydropower are also being considered for hands-on activities for the spring 2011 course.

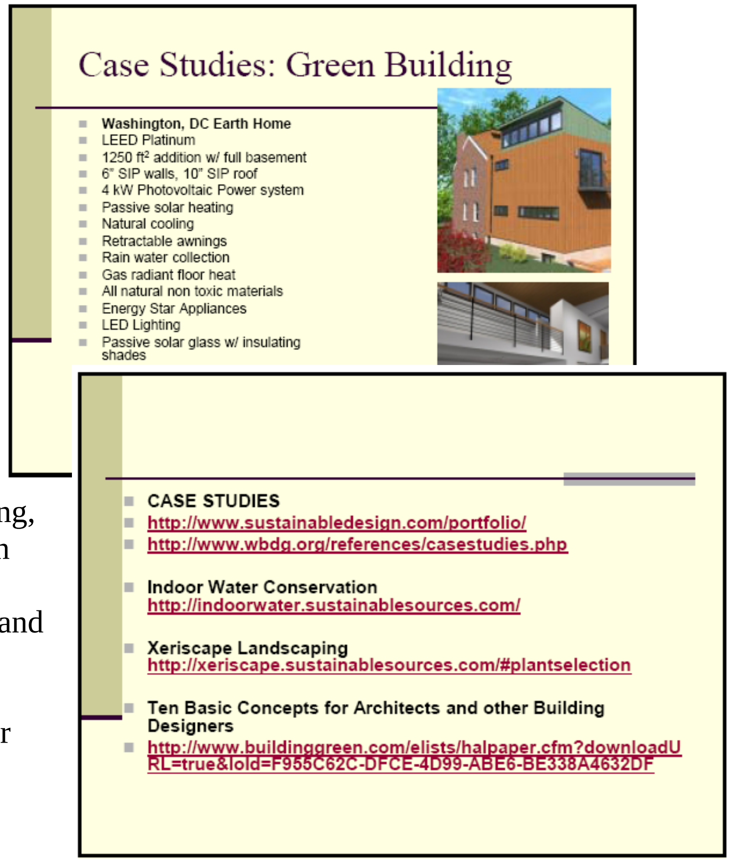

Figure 2. Example of Case Studies used in Green building presentation

Summary of Activities

1) Week 1: Review Case examples, select building, In class worksheet
2) Week 2: Tour of Proximity hotel – Students participated in a tour of a LEED Platinum certified hotel and restaurant.
3) Week 3: Students work on building designs and in-class discussion with professor
4) Week 4: Presentation of their project

Module 2: Rainwater Harvesting, Water Recycling, and Reuse (6 weeks)

Students were asked to propose a design featuring water recycling, harvesting, and/or reuse system for the NCA&T football stadium. Students were taken to the football stadium during week 1 of the module to discuss the current water handling and their initial understanding of water quality. Students were asked to research water quality issues and the analysis that would be needed to test recycled water, surface water, and rainwater water. The goal was to have the students in the group to determine which water testing analysis were needed. The student/teacher discussions about water analysis formed the basis of the series of laboratory experiments conducted during week 3 – 5. Student discussions led them to determine they would need to be able to measure water quality parameters such as pH, turbidity, chemicals and microorganisms. Through the discussion we identified their need to gain skills in measuring Nitrogen, Phosphorus, Hardness, Ammonia, BOD/COD, TDS/TSS/SS, dissolved oxygen, fecal coliform and turbidity. In a traditional laboratory course, the professor would weekly assign these laboratory tasks topics. By using the PBL project as the basis and the student led discussion, the students had to opportunity to identify the analyses first and then learn how to conduct lab experiments to measure these parameters. Therefore, students directly understood why they were conducting the experimental analysis before given the experiment procedures. Using the method of discussing the methods first and then running the experiment resulted in the students being more engaged during the lab experiments. The students also understood the direct link between the analyses they were learning during lab and how it linked to their projects.

Students were allowed to bring in their own water samples with the professor's permission and the professor provided samples of rainwater, well, and surface water from a local park contaminated with fecal coliform. The students learned how to analyze the samples nitrogen, phosphorus, hardness, ammonia, BOD/COD, TDS/TSS/SS, dissolved oxygen (Experiments 1 and 2). The students conducted a simple a water filtration project where they were provided materials such as sand, gravel, activated carbon to use physical methods treat water (Experiment 3) and they learned how to conduct membrane filtration (MF) to quantify total coliform in water (Experiment 4). To conclude the series of lab experiments, the student learned microscope skills and how to collect and grow bacteria from surfaces using streak plates (Experiment 5). After the experiments, students completed their projects and presented their work.

Summary of Activities

1) Week 1: Site visit to the stadium - students walked the stadium and discussed ideas for sustainable projects.
2) Week 2 - 3: Discussion and Water quality testing
3) Week 4: Membrane Filtration
4) Week 5: Streak plates and swab sampling for microorganism
5) Week 6: Presentation of their design

Year 1 Assessment

Teaching/Learning Preferences and ABET Post Assessment

Student perception of the PBL and case studies used during the laboratory course activities were assessed with focus group interviews, a final survey and an ABET assessment. The surveys were designed to assess the benefit of various teaching techniques, interventions, and tools. In the first survey, students were asked if they to Strongly Agree, Agree, Neutral, Disagree, or Strongly Disagree to the teaching/learning method contributed their learning (Table 2). The second survey was the ABET based assessment conducted for the course (Table 3). For the final assessment, 12 of the initial 19 students completed the surveys. We had difficulty with the on-line assessment tool for the post SALG assessment. The on-line tool did not record data for the post survey responses. Our solution was to provide a hardcopy survey to the students. Due to the computer survey difficulty and the voluntary nature of the survey participation, we did not receive responses from all of the students. Additionally we had two students who withdrew from the course or University due to personal or medical reasons before the end of the semester.

Discussion

Lessons learned: Student feedback

Preliminary feedback from the student interviews suggests 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 students particularly enjoyed the real world approaches and seeing how they could expect to apply course lab skills to their real jobs after graduation. They felt some aspects of the labs were similar to the traditional lab format, yet the problem based learning and real-life scenarios added a new spin on the topics that made them more interesting. Students also indicated they did not know their learning style until completing the ILSS on-line survey.

The students recommended that the course could be improved by having more time outside of the classroom for site visits and field visits. The class groups felt they looked at a wide variety of similar topics and felt if under the "umbrella" of the topic such as green engineering if each group focused on one specific area for the topic and then presented the material to the class they would have the opportunity to go into more depth. The surveys for student's preferences for teaching and learning (Table 2) and the student's opinion of their learning gains (Table 3) provided a number of interesting results.

Table 2. Year 1: Post-course Assessment of Student Preferences for Teaching and Learning (n=12)

	Number of Students indicating their abilities and preferences for Teaching and Learning				
	Strongly Agree	Agree	Neutral	Disagree	strongly disagree
The use of problems and performing calculations	67%	33%	0%	0%	0%
Working in groups (1 student indicated - no response)	67%	17%	8%	0%	0%
Communicating about environmental engineering including sustainability with your group members	75%	25%	0%	0%	0%
Peers as teachers	42%	33%	25%	0%	0%
Working individually on assignments	17%	42%	33%	8%	0%

Table 2. Year 1: Post -course Assessment of Student Preferences for Teaching and Learning (continued)

	Number of Students indicating their abilities and preferences for Teaching and Learning				
	Strongly Agree	Agree	Neutral	Disagree	strongly disagree
Class discussions led by the professor	75%	25%	0%	0%	0%
Class discussions led by classmates	17%	42%	33%	8%	0%
Lectures by the professor	8%	83%	0%	0%	8%
The coursepack of readings or course reading materials	33%	42%	17%	0%	8%
The use of electronic resources, primarily the Internet, to find information	75%	17%	8%	0%	0%
Library resources, other than electronic ones	8%	33%	17%	42%	0%
The use of computers as an investigative tool	83%	17%	0%	0%	0%
Communicating literature and/or research results	50%	50%	0%	0%	0%
Participating in discussions	67%	33%	0%	0%	0%
Writing about environmental issues	33%	50%	17%	0%	0%
Working collaboratively with classmates	58%	25%	17%	0%	0%
Finding relevant information	58%	33%	8%	0%	0%
Analyzing and synthesizing information	58%	33%	8%	0%	0%
Using computers for information retrieval and data analysis	50%	50%	0%	0%	0%
Thinking critically about environmental issues	83%	17%	0%	0%	0%
Communicating and solving problems related to environmental technology, air, water, and soil contamination	100%	0%	0%	0%	0%
Communicating and discussing the role of microorganisms in environmental engineering	50%	42%	8%	0%	0%
Communicating about environmental engineering, microbiology, and biotechnology topics in a class workgroup	33%	50%	17%	0%	0%

Table 3. Year 1: ABET Based Questionnaire for Post-course Assessment (n=12)

Assess your ability and level of knowledge for the following:	very knowledgeable	somewhat knowledgeable	not sure	somewhat unknowledgeable	very unknowledgeable
1. Name, describe or use environmental engineering definitions and definitions for sustainability	58.33%	41.67%	0.00%	0.00%	0.00%
2. Name, describe or use environmental engineering concepts	58.33%	41.67%	0.00%	0.00%	0.00%
3. Name, describe or use environmental nomenclature for calculations	25.00%	41.67%	33.33%	0.00%	0.00%
4. Ability to identify, formulate, and solve environmental mass balances	75.00%	25.00%	0.00%	0.00%	0.00%
5. Understanding professional and ethical responsibility in environmental engineering	75.00%	25.00%	0.00%	0.00%	0.00%
6. Ability to effectively communicate about an environmental topics	41.67%	50.00%	8.33%	0.00%	0.00%
7. Ability to design and test experiments for environmental research	25.00%	66.67%	8.33%	0.00%	0.00%
8. Broad education necessary to understand the impact of engineering solutions in a global and societal context	33.33%	66.67%	0.00%	0.00%	0.00%
9. Recognition of the need for and an ability to engage in life-long learning	50.00%	41.67%	8.33%	0.00%	0.00%
10. Knowledge of contemporary environmental issues	50.00%	41.67%	8.33%	0.00%	0.00%
11. An ability to use these techniques, skills, and modern engineering tools necessary for engineering practice	41.67%	33.33%	16.67%	8.33%	0.00%

Table 2 addresses student opinion for their abilities and the teaching methods that helped them to learn in the course. From the survey, 75% or more students strongly agreed they benefited from discussions about environmental engineering and sustainability with the professor, use of electronic resources and computers for research, and thinking critically about environmental issues facilitated learning in the course. The students also strongly agreed at 50% that they benefited by collaboratively working with classmates, participating in discussions, and analyzing and synthesizing information. Students favored the "agree" or "neutral" response for discussions led by classmates, course pack reading, writing about environmental issues, and working individually on assignments for improving their learning.

Table 3 is the ABET post-course assessment conducted for the Environmental Lab Course to measure the effectiveness of the course to meet ABET learning objectives. More than 50% of the students considered themselves to be "very knowledgeable" by the end of the course for understanding environmental engineering, sustainability, and ethic responsibilities as an engineer. Students indicated they were "somewhat knowledgeable" for designing experiments which may be due to a lack of confidence in designing an experiment independently without guidance from an instructor. We also hope to improve during year 2 student perception of their ability to implement these skills in engineering practice.

Lessons Learned: Faculty Perspective

We discovered based on student feedback that more time was needed for the students to develop metacognition to facilitate skills like concept organization, relationships and monitoring one's own learning progress. These areas in the course can be improved upon by providing more guidance as the students create their projects and secondly the students needed more opportunities to reflect upon what they know about themselves and their learning process.

The PBL and case study method required more faculty preparation time for the projects and the case studies selected for the lab. Implementation in the course required a very organized approach to guiding the students and maintaining a schedule to accomplish course objectives. Using PBL and case studies to introduce the experiments is not as formal or structured as a traditional step-by-step laboratory course. The faculty in charge of the course does not have structured control of having a weekly schedule for lab experiments. The amount of interest the students demonstrated in their designs was exciting to observe because the students were engaged and actively participated in the discussion for their projects. The original goal of the course was to offer Green Engineering, Water Recycling, Biodegradable Polymers, and Solid waste handling. Due to time constraints in the amount of time the case study/PBL method needed, we would have had difficulty trying to implement all four modules during year 1. After year 2, we may determine the shorter case studies teaching method is more practical for an undergraduate laboratory than PBL. PBL may be more appropriate for an advanced two-semester lab course or graduate course due to the time constraints and student skill level.

Closing

Spring 2011 will begin year 2 of educational research in the Environmental Engineering Laboratory course. We will work to improve the first two modules and expect to be able to add the biodegradable polymer and solid waste/recycling modules. During the Year 1 group interviews, the students expressed they were not interested in learning about biodegradable polymers and would prefer to focus more on green engineering, water sustainability, and solid waste/recycling. For year 2, we will have both pre- and post- surveys for the SALG, Student Teaching and Learning Assessment, and ABET assessment. We have also improved our use of the on-line survey instruments to collect data. We attempted to use the SALG tool during year 1 and had difficulty with implementation therefore we will use the on-line Survey Monkey tool to collect data. Focus group interviews will also collect student feedback for year 2. The results from year 1 and year 2 will be summarized in future publications and the modules developed for the course will be available and shared with instructors at other Universities through our departmental website.

References

1. Bransford, J., Brown, A. and Cocking, R. How People Learn: Brain, Mind, Experience, and School. Washington, DC: National Academies Press, 1999.

2. Roy, H. "Studio versus interactive lecture demonstration- Effects on student learning". BioScience, 2003, 29:3-6.

3. Waterman, M.A. and Stanley, E.D., "Investigative Case Based Learning: Teaching Scientifically while connecting Science to Society". CCLI Conference 2008. Successful Pedagogies. Available online:[http://www.aaas.org/publications/books_reports/CCLI/PDFs/03_Suc_Peds_Waterman. pdf].

4. Yeung, E., Au-Yeung, S. Chiu, T., Mok, N., Lai, P. "Problem Design in Problem-based Learning: Evaluating Student's Learning and Self-directed Learning Practice". Innovations in Education and Teaching. 2003. Vol 40(3). 237–241.

5. Chung, J. and Chow, S. "Promoting student learning through a student-centered problem-based learning subject curriculum". Innovations in Education and Teaching International, 2004, Vol 41(2). 158–168.

6. Donovan, Bransford & Pellegrino, "How People Learn: Brain, Mind, Experience, and School: Expanded Edition", Commission on Behavioral and Social Sciences and Education, 1999.

7. Flavell, J. H. Metacognitive aspects of problem solving. In L. B. Resnick (Ed.), The Nature of Intelligence. Hillsdale, NJ: Erlbaum, 1976. 231-236.