AC 2010-1752: ENGAGING STUDENTS IN CRITICAL THINKING: AN ENVIRONMENTAL ENGINEERING EFFECT

Nicole Berge, University of South Carolina

Dr. Nicole Berge received her BS and MS degrees in Civil and Environmental Engineering from the University of South Carolina in 1999 and 2001, respectively. In 2006, she received her PhD in Environmental Engineering from the University of Central Florida. From 2006 – 2008, Dr. Berge worked as a Postdoctoral Associate at Tufts University. Currently, she is an Assistant Professor at the University of South Carolina.

Joseph Flora, University of South Carolina

Dr. Joseph Flora is currently an Associate Professor at the University of South Carolina. He received his BS degree in Civil Engineering from the University of the Philippines in 1987 and his MS degree in Environmental Engineering from the University of Illinois at Urbana-Champaign in 1990. In 1993, Dr. Flora received his PhD in Environmental Engineering from the University of Cincinnati. Dr. Flora has been at the University of South Carolina since 1993.

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Introduction

Engineering education research suggests that undergraduate engineering education should evolve from traditional lecture style instruction to models involving student centered (or active learning) techniques, such as collaborative, inquiry, and problem-based learning. Incorporation of activities invoking student involvement during class meetings has been shown to foster development of critical thinking and problem solving skills, as well as creativity and innovation, while enhancing retention of course material.[1-5] The type of activity employed will likely dictate the degree of critical thinking and problem solving skill development, as well as the degree of material retention.

Integration of such activities may occur within a class meeting (such as relatively short activities) or may play a more major role. Short activities that periodically engage students during class break up the monotony of traditional lectures and likely provide an opportunity for students "to start fresh again".[6] Inquiry-based activities have been incorporated into undergraduate laboratory classes.[1,7,8] During these activities, the students are responsible for posing a question, hypothesizing the outcome, developing an experiment to test their hypothesis, analyze data, and report their results. Activities of this type have been shown to increase learning and improve the overall laboratory experience.[7,8] Martin et al.[3] compared student performance in an inquiry-based and traditional lecture style biomedical engineering course. Results indicated that the degree of student acquired core knowledge did not differ between the instructional techniques, but students in the inquiry-based course demonstrated significant improvement in "innovative thinking abilities." These observations were corroborated by Leon-Rovira et al.[9]; the authors also found that student creativity was enhanced as a result of integration of active/inquiry-based techniques. Problem-based learning approaches have also been employed and resulted in positive student feedback.[6] Some curricula are integrating entire courses (predominantly upper level design courses) based on such techniques. Quinn and Albano[4] report on a problem-based learning course (i.e., senior year project) in structural engineering in which student feedback is positive. A problem-based capstone senior design course being taught at the University of South Carolina is an important aspect of the curriculum. During this course, students are grouped into multi-disciplinary teams and provided a design problem. The timing of such activities is also critical. Mullins et al.[10] found that even after one semester of a freshman engineering program, student's design processes (i.e., problem solving time, more iterative approach) significantly improved, although the overall quality of the design did not. Cardella et al.[11] observed mixed results when comparing student designs as freshman with those when they are seniors. Two of the students showed improvement, while two did not.

At the University of South Carolina (USC), we incorporated active learning exercises to enhance critical thinking skills in an elective introductory civil engineering course (ECIV 101: Introduction to Civil Engineering). The course was restricted to incoming freshmen. The course introduces students to different civil engineering sub-disciplines, including structural, geotechnical, water resources, transportation, environmental engineering, and surveying. Each subdiscipline is organized around a module, or Environment For Fostering Effective Critical Thinking (EFFECT). An EFFECT is designed to elicit critical thinking skills and enhance the transfer of core knowledge.[12] The pedagogical structure of an EFFECT is as follows: 1) an individual and group decision worksheet that guides an initial design during the first class period, 2) active learning modules and journal questions during the next several class periods, and 3) group discussion during the final class period that guides the final design, which culminates in the submission of a final report.

This paper describes educational efforts in developing and implementing an environmental engineering EFFECT. During this module, students are posed with the challenge of designing a water filter for a small community. The feasibility of the initial design solution is investigated through a series of student-led active learning modules by discussing or testing some of their design assumptions. Students build a filter, quantify dye removal, and test for scale up. After each class, students submit a journal response to specific questions about class activities, explaining how and why the material learned in that class helps them in their design, and how this new knowledge has impacted or changed their initial design. Journal submittal and assessment is performed with an in-house on-line tool developed with a rubric specifically designed to evaluate core knowledge and critical thinking. The on-line tool has built-in metric assessment, and the rubric has been shown to have inter- and intra-rater reliabilities greater than 0.7. The final class of an EFFECT is used to discuss what was learned during the active learning experiences to determine the most appropriate design solution within the context of this new knowledge. Students work in their design groups, review their decision worksheets, and discuss and estimate the factors to consider in their design. Students submit an individual final report with their design.

Design and Implementation of the Environmental Engineering EFFECT

The initial design of the environmental engineering EFFECT occurred in 2007, was pilot-tested in Summer 2007 at a USC Science and Engineering Summer Camp offered primarily to minority high school students, and was implemented in ECIV 101 during the Fall 2007 semester. Using student feedback and instructor reflection, slightly modified versions of the EFFECT were subsequently implemented during the Summer 2009 high school camp and the Fall 2009 ECIV 101 class. This section describes the evolution of the EFFECT.

Initial EFFECT implementation in ECIV 101

The environmental engineering EFFECT was designed to be implemented in four 2-hour class meetings. During the first meeting, a decision worksheet was given individually to students. The decision worksheet was composed of an introductory statement describing the problem, with the ultimate goal of a filter design. Four subsequent questions were also asked to help guide student's thinking. Table 1 shows the components of the decision worksheet. In general, students were given minimal guidance in answering questions. Students were then arranged in groups of four and were tasked with coming up with a group response to the decision worksheet. Each group presented their design at the end of the class period.

Table 1. Decision worksheet implemented in Fall 2007 and 2009.

Problem Statement: As an engineer, you are asked to design a water treatment system for a small community that includes a filter. The water source is a river that contains high concentrations of organic compounds that must be removed using the filter. What would be the dimensions of the filter?	
2007 Questions	*2009 Questions*
1. Make a sketch of the activated carbon filter. What are the bases for your shape and dimensions? 2. What factors do you think you must know so you can provide a reasonable estimate? Why? 3. Estimate values for these factors. 4. What would you consider failure of AC filter. How might you have done things differently?	1. Make a sketch of the filter. What are the bases for your shape and dimensions? What materials would you use? 2. What factors do you think you must know so you can provide a reasonable estimate? Why? 3. Estimate values for these factors. How confident do you feel about these estimates and why? 4. What would you consider failure of the filter? Why?

Students performed laboratory experiments to evaluate how much dye activated carbon could remove in the subsequent two meetings. The principle of how a spectrophotometer can be used to measure the concentration of a dye was explained but explicit laboratory procedures were not given. During the second meeting, students had to determine how to generate a calibration curve to evaluate the extent of decrease of dye concentration in the presence of activated carbon. During the third meeting, students were asked to build a filter using a syringe and activated carbon and to subsequently test how much dye the filter could remove. Guidelines for the final report were given during the fourth meeting (see Table 2). The students were given the opportunity to ask questions that would help in their design scale-up. Questions raised were related to the population of the community, the typical water usage per capita, the required removal efficiency, the design life of the filter components, how to calculate adsorptive capacity, and how to determine the mass of activated carbon required. Answers were provided to some questions (e.g., a range of per capita water usage was given). Indirect guidance was given as to calculations of adsorptive capacity and mass requirements with the intent that students should be able to extract this information by performing material balances.

Students were also required to answer journal questions prior to the first meeting, as well prior to subsequent meetings. Palmer [13] reported that students found the use of a reflective journal, specifically for comparison to other student responses, aided in the learning of course material. The journal questions are presented in Table 3. Student responses to the journal entries were evaluated using an on-line assessment tool with the rubric shown in Table 4.

Table 2. Final Report Guidelines in Fall 2007 and 2009.

Problem Statement: Your engineering consulting firm has been charged with the task of developing a preliminary design for an activated carbon filter as part of a drinking water treatment plant for a small community. You must prepare a report that answers the following question: What are the dimensions of the filter?
The written report must contain the following sections:
1. Introduction: Introduce the problem and describe why this driving question is important. 2. Design: Your answer to the driving question should be supported with the following: • Discussion of how you determined the adsorptive capacity of the carbon for a target compound (i.e., how much mass of compound is removed per mass of carbon). • Discussion of how you determined the mass of carbon required. As part of this, you would need to *explicitly* state any assumptions you may have made. • You must include plots that will help document your calculations. As an engineer, you must be very meticulous with documentation so someone in the future can go through your calculations and understand what you did. 3. Lessons Learned: How has your preliminary design changed from the first day [when you completed the decision worksheet]? What things did you learn that affected these changes? Discuss.

Table 3. Journal Questions implemented in Fall 2007 and 2009.

2007		2009	
Day Assigned	Question	Day Assigned	Question
Prior to EFFECT	What do you think environmental engineers do? What type of classes should one take to be a successful environmental engineer?	1	What factors did you not consider in your initial (individual) design of the filter? Why are these factors important and how would these change your initial design?
1	What types of questions do you need to ask when confronted with a design problem? How might one measure the concentration of a contaminant?	2	Describe one approach how you might measure the concentration of a contaminant. How can you use this information in designing your filter?
2	What concepts did you learn today that will impact your approach to designing the filter? Why? How can you quantify the amount of dye that the activated carbon removes?	3	Describe how you might use the concepts learned in the past three meetings to change your initial filter design (your individual design last Monday)? Why would you make these changes (if any)?
3	What concepts did you learn today that will impact your approach to designing the filter? Why? How does the past two days change your idea of designing an AC filter?	4	How would you use the concepts learned in the past four meetings to calculate the amount of dye removed from a full scale filter that you must design? How confident are you about your approach, and why?

Table 4. Critical Thinking Rubric.

Core Knowledge	Critical Thinking
1. Vague: Student discusses engineering concepts but does not use specific terms or details.	1. Unreflective: No evidence of critical thinking.
2. Inaccurate: Student uses one to a few specific terms, and may have inaccuracies or misconceptions.	2. Novice: Student uses at least one observation to draw a conclusion. Reasoning may be vague or contain some faults. The student makes connections from material directly from class.
3. Accurate: Student uses several specific terms and the majority of them accurately.	3. Reflective: Student uses multiple observations to draw a conclusion. The majority of reasoning must be valid. Student makes new connections among topics within the course.
4. Sophisticated: Student demonstrates completely accurate knowledge about multiple concepts.	4. Metacognitive: Student demonstrates awareness of their learning. Student uses multiple observations to make a completely valid conclusion, makes connections to ideas outside the class, and transfers their knowledge to other situations outside the course.

Revised EFFECT Implementation in ECIV 101

An end-of-the-semester evaluation of the different EFFECTs implemented in ECIV 101 (2007) revealed that journal questions must be revised to elicit better core knowledge and critical thinking responses. The first question specifically targeted core knowledge, and the second question targeted critical thinking. These revised journal questions are shown in Table 3.

Furthermore, based on experiences with other EFFECTs where materials were limiting laboratory performance, it was decided to implement economic restrictions on the use of materials. Each group was provided a fixed amount of money to buy the supplies necessary to build an effective filter. In addition to providing students activated carbon, filter materials including gravel and sand were made available. Material prices were scaled based on market values. Introducing the concept of money required the students spend time developing a strategy for their design. Materials were sold on a weight basis (smallest amount purchasable was 1 gram). Because the students were confined to a specific filter volume, this required they consider material densities. The decision worksheet was slightly changed and is shown in Table 1.

Implementation of the EFFECT during the High School Summer Camp

For each implemention in the Fall ECIV 101 class, the high school summer camp served as a pilot. Hence, the implementation of the EFFECTs was similar to that described previously. The difference in the Summer 2007 EFFECT was that more explicit procedural guidance was given to the high school students. This procedural guidance was scaled back during the Summer 2009 EFFECT. The high school students were still able to complete their work despite the reduced guidance, indicating that their critical thinking was not hindered. The students still produced a design that met expectations of the instructors. Another difference during the Summer 2009 implementation is that following the student's initial filter design, each group presented a brief oral report including their filter design, dye removal efficiency, and something they thought was good and bad about their design. Using the knowledge they gained from their initial design and from the other groups, each group redesigned their filter in an attempt to achieve greater removal efficiency. Group discussions during the redesign phase of the exercise demonstrated critical thinking and resulted in more effective designs.

Assessment

Results from an end-of-class questionnaire completed by students enrolled in the ECIV 101 course (2007 and 2009) were used to evaluate the effectiveness of the environmental engineering EFFECT and to gauge students' perception of how different tools employed throughout the course aided in the development of critical thinking skills. Presented in Figure 1 are the survey results associated with the implementation of the environmental engineering EFFECT during both the 2007 and 2009 ECIV 101 course. Results indicate that despite a general lower interest level in environmental engineering, the students did find the EFFECT interesting. The modified EFFECT implemented in 2009 was found to be of more interest than the initial exercise. Results also indicate the students strongly believe they learned about environmental engineering (average scores of 2.73 and 2.88). One student (from the 2009 course) commented that "the hands on experiments taught me a lot. Especially that other aspect of engineering such as environmental and geotechnical are more interesting than I originally thought." In comparison with other EFFECTs implemented during the 2009 course (see Figure 2), the environmental engineering module was rated comparably. The students perceived to have learned as much about environmental engineering as other areas they generally find more interesting.

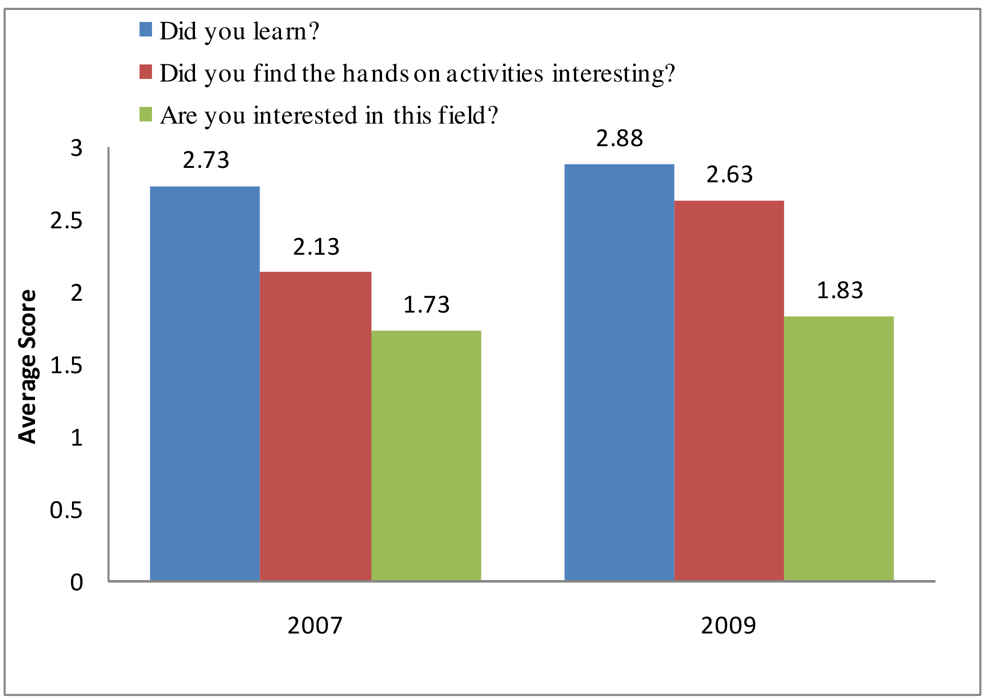

Figure 1. Comparison of average scores from end-of-the-semester evaluations associated with the environmental engineering in EFFECT. Students were asked to respond with a numerical value ranging from 1 to 3 where: 1 = not interested/disagree; 2=neutral; and 3=interested/agree. Sample sizes were 15 and 24 in 2007 and 2009, respectively.

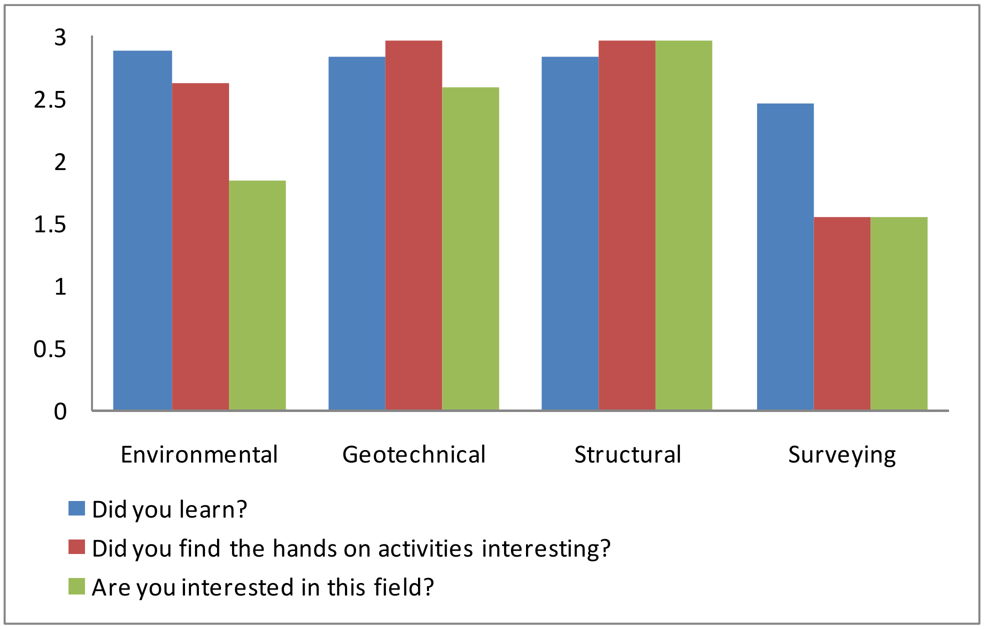

Figure 2. Comparison of average scores from end-of-the-semester evaluations associated with all EFFECTs presented during the 2009 ECIV 101 course. Students were asked to respond with a numerical value ranging from 1 to 3 where: 1 = not interested/disagree; 2=neutral; and 3=interested/agree. Sample size was 24.

Survey questions were also directed to evaluate the effectiveness of the course in developing critical thinking skills. Students were asked to evaluate how different course tools (decision worksheets, group discussions, journal entries, hands-on activities, and final reports) helped them develop critical thinking skills and answer questions posed by each EFFECT. Results are presented in Table 5. Overall, 58.3% of the students felt the course was either helpful or very helpful towards the development of critical thinking skills. Less than half of the class felt the decision worksheets and journal entries aided development of critical thinking skills, however a majority of students felt these items were helpful to answering the questions posed during each EFFECT. Almost the entire class felt the hands-on activities contributed to development of critical thinking skills and to helping solve the questions posed in the EFFECT.

Table 5. Survey Responses (2009 course) Associated with Helpfulness of Course Tools.

	Helpful for developing critical thinking skills (%)	Helpful for solution of driving question (%)
Decision Worksheets	37.5	62.5
Group Discussions	58.3	95.8
Journal Entries	48	62.5
Hands-on Activities	95.8	100
Final Reports	66.7	n/a
Overall Class	58.3	n/a

Note: Numbers represent the percentage of students that felt the item was either very helpful or helpful. Sample size is 24.

Summary

The Environmental Engineering EFFECT was implemented in an undergraduate introductory civil engineering class and subsequently revised. Results suggest that the modifications were beneficial. Students' perception of activities improved between implementations. Immediate student verbal feedback was positive. However, some short comings of the revised exercise were revealed. The students encountered some difficulties while conducting the modified EFFECT. At this stage in the student's academic program, they have not yet been exposed to important concepts, such as conservation of mass, which complicated the students' ability to connect their experimental results to filter scale up. For example, while students understood how to evaluate which material was the best adsorbent for the dye, they had difficulty in connecting their sorption data to the scale-up of their filters (how much filter material is necessary to remove a certain dye concentration). These challenges will be addressed in a further revision of the EFFECT.

During the pilot implementation with the high school students, although students were able to design more effective filters and gained a basic understanding associated with removal efficiencies, and to some degree sorption, there was no exercise for the students to assess which material was most effective, nor was there a means for them to gain a "real" perspective of what their results mean (i.e., scale-up). All students commented that activated carbon was likely the most effective at removing the contaminant, however, conducting an exercise for the students to test this hypothesis would have been beneficial. Overall, the level of activities were appropriate for the high school students.

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