Engineering EFFECTs: Strategies and Successes in Introduction to Civil Engineering

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***Abstract* – This paper describes the development, implementation, and assessment of engineering Environments for Fostering Effective Critical Thinking (EFFECTs) that serve as the core instructional materials in an Introduction to Civil Engineering course at the University of South Carolina. In this course, the goals are to i) expose first-year students to the disciplines of civil engineering, including environmental, geotechnical, structural, transportation, and water resources engineering; ii) provide opportunities for students to acquire fundamental knowledge in civil engineering, while gaining skills for success in a challenging academic environment; and iii) encourage students to recognize and develop critical thinking skills that will serve as the foundation for growth in engineering judgment. Based on a five-year review of this course, these three goals are being achieved in large part because of the educational strategies built into EFFECTs. This pedagogical approach integrates active learning techniques, reflective writing, and iterative engineering design into a framework centered on a driving question that relates to a real engineering context or problem. Student satisfaction and perception of learning earn consistently high ratings; hands-on activities and in-class interaction are two of the contributing factors. Most importantly, the course has had a measureable impact on sophomore retention.**

Index Terms – Active learning, Civil engineering, Critical thinking, First-Year engineering, Retention

INTRODUCTION

In 2007, Introduction to Civil Engineering (ECIV 101) was approved as a technical elective in the Bachelor of Science program in Civil and Environmental Engineering at the University of South Carolina. Prior to that, all first-year civil engineering students enrolled in Introduction to Engineering Graphics (ECIV 111), which served as the de facto introductory course to the major. However, ECIV 111 was not designed to expose students to the disciplines within civil engineering, nor did it provide strategies for success as a first-year student in a rigorous academic environment. There were two significant advantages with offering this new course as an elective rather than a requirement: 1) course enrollments were sufficiently manageable to allow for a high level of instructor-student and peer-peer interaction; and 2) the course impact on retention could be evaluated, since first-year civil engineering students enrolled in either ECIV 101 or ECIV 111, with a few exceptions. In ECIV 101, a new pedagogical approach was introduced to stimulate critical thinking while learning about civil engineering. This paper provides a five-year review of the implementation and assessment of Introduction to Civil Engineering at the University of South Carolina.

COURSE STRUCTURE FOR INTRODUCTION TO CIVIL ENGINEERING (ECIV 101)

ECIV 101 is designed to achieve three objectives. According to the syllabus, students will:

1. Learn practical skills to succeed as a student;
2. Understand civil engineering as a whole profession and understand basic concepts in different fields such as Surveying, Environmental, Geotechnical, Structural, Transportation and Water Resources Engineering; and
3. Have the ability to apply basic critical thinking skills in the context of engineering problems.

A blended model was developed to achieve these three course objectives. In this model, Objective 1 was met using instructional material from Landis [1]. This content was delivered through interactive lectures combined with small group discussions. Objectives 2 and 3 were met using instructional materials developed specifically for this course, called Environments for Fostering Effective Critical Thinking (EFFECTs). This content was delivered through a connected series of active learning exercises that include hands-on exploration, small group discussion, and open dialogue with the entire class. Since the course has a significant experimental component, there are four hours of contact time; class periods are scheduled for two hours twice per week, which affords sufficient time for high levels of interaction. In addition, the course is taught by a team of three tenured faculty members in the Department of Civil and Environmental Engineering. There are often two, and sometimes three, instructors in class at the same time, which enhances the breadth and depth of in-class discussions. The three course objectives are mapped to four of the ABET EAC Criterion 3: Student Outcomes [2]:

- b. ability to design and conduct experiments, as well as to analyze and interpret data;
- e. ability to identify, formulate, and solve engineering problems;
- g. ability to communicate effectively; and

i. recognition of the need for, and an ability to engage in life-long learning.

ECIV 101 is structured to balance the use of instructional materials on a week-to-week basis. For example, the most recent course schedule was organized as follows:

- Week 1: Introduction
- Weeks 2-3: How can you succeed in engineering?
- Weeks 4-5: EFFECT 1 – Civil Engineering Measurements (Surveying)
- Week 6: How good are your problem-solving skills?
- Weeks 7-8: EFFECT 2 – Geotechnical Engineering
- Week 9: How can you get involved outside of classes?
- Weeks 10-11: EFFECT 3 – Environmental Engineering
- Week 12: What is your career path?
- Weeks 13-14: EFFECT 4 – Structural Engineering
- Week 15: Closure

The EFFECT on Civil Engineering Measurements (Surveying) provides coverage of some fundamental engineering concepts and basic computing skills. For these reasons, it has been permanently assigned as the first EFFECT. The order and content of the next three EFFECTs can change, depending on the instructional team's schedule. In the Civil and Environmental Engineering curriculum at the University of South Carolina, there are five distribution areas at the upper division: environmental, geotechnical, structural, transportation, and water resources engineering. Thus the goal is to introduce first-year students to at least three of these five areas using EFFECTs.

TABLE I
EFFECTS IN INTRODUCTION TO CIVIL ENGINEERING
(FALL 2007 – FALL 2011)

EFFECT Content	Driving Question	Instructional Frequency
Environmental: *Nanotechnology*	How many nano-sized iron particles are needed to remediate 15 trillion gallons of groundwater contaminated with trichloroethylene (TCE)?	1 (2011)
Environmental: *Oil Spill*	How much surfactant should be added to remediate an oil spill?	2 (2009, 2010)
Environmental: *Water Filtration*	What are the dimensions of the activated carbon filter needed in the water filtration system for a small community?	1 (2007)
Geotechnical: *Levee Reconstruction*	What weight of soil is needed to construct a 100-ft long section of earthen levee?	5 (2007-2011)
Structural: *Earthquake Response*	What shape of the water tower support structure is needed to avoid its collapse during an earthquake?	4 (2007-2010)
Surveying: *Parking Lot*	What is the area of the parking lot that should be used to calculate the volume of concrete?	5 (2007-2011)
Transportation: *Hurricane Evacuation*	How much time is required for safe evacuation from an approaching hurricane?	1 (2007)
Water Resources: *Water Tower*	How tall should a new water tower be to serve a small community?	3 (2007, 2008, 2011)

Table I shows the civil engineering areas that have been introduced through EFFECTs during the past five years. It should be noted that, in the Fall 2007 semester, students were exposed to all five distribution areas, in addition to surveying. Student feedback indicated that six EFFECTs were too intensive. This high exposure led to reduced student interest and performance near the end of the semester because of the high workload demands and onset of instructional repetition (since EFFECTs utilize the same framework, as described in the next section). It was determined that four EFFECTs represented an ideal number. This reduction also enabled the expansion of material from Landis [1].

EFFECTS PEDAGOGICAL FRAMEWORK

Critical thinking in first-year engineering courses has been the recent subject of engineering education literature [3-12]. Research shows that critical thinking can be facilitated through active learning, and it can be further stimulated and evaluated through the careful design of reflective writing assignments. The pedagogical framework for EFFECTs, or Environments for Fostering Effective Critical Thinking, links the two critical elements of active learning and reflective writing within the context of a realistic engineering design problem. Lipman [13] defines critical thinking as "skillful, responsible thinking that facilitates good engineering judgment because it relies upon criteria, is self-correcting, and is sensitive to content." EFFECTs are designed on the basis of this definition.

The crux of each EFFECT is the formulation of a driving question that relates to a real engineering context or problem. Table I identifies the driving question for each EFFECT in ECIV 101. Driving questions are designed to first elicit student interest and then generate motivation for acquiring particular pieces of content knowledge and engineering concepts to solve the problem. As shown in Table I, each question calls for a quantitative response, such as the weight of soil needed for a levee or the height required for a new water tower. Solutions to the driving question are updated as students accumulate knowledge during the EFFECT sequence.

As shown in Figure 1, the instructional sequence begins with a decision worksheet and concludes with a final design report. Each student provides an initial solution using the decision worksheet, and the design report contains the final, revised solution. In between, there are n class periods with active learning modules that lead to student understanding of engineering concepts relevant to the driving question. In ECIV 101, the in-class completion of decision worksheets is followed with two or three consecutive classes with active learning modules. Most EFFECTs are two weeks in length, which equates to eight hours of contact time. Examples of engineering EFFECTs can be found in Wait [5] and Berge and Flora [7].

Decision worksheets have three core elements: 1) context, 2) driving question, and 3) guiding questions. Figure 2 shows an example of a decision worksheet for geotechnical engineering, which is set in the context of post-Katrina reconstruction of New Orleans. The decision worksheet requires students to make assumptions or estimations based on prior knowledge, regardless of the extent of that knowledge, in support of an initial solution to the driving question. In this case, students are probed about their knowledge of geometrical shape, dimensions, and volumes of earthen levees and the corresponding weight of soil that occupies a given volume, i.e., soil density. Through the guiding questions, the decision worksheet also elicits self-identification of information or knowledge that is lacking in order to answer the driving question. It is important to note that *how* and *why* questions are embedded within the guiding questions, which enables the documentation and evaluation of the student's thought process. Individual worksheets are completed first, and then students collaborate in teams to complete a group worksheet using smart pens and notebooks. Small group discussions provide opportunities for students to compare misconceptions or partial understandings of the problem, and the dialogue often raises ideas or thoughts that will be confronted in subsequent exercises.

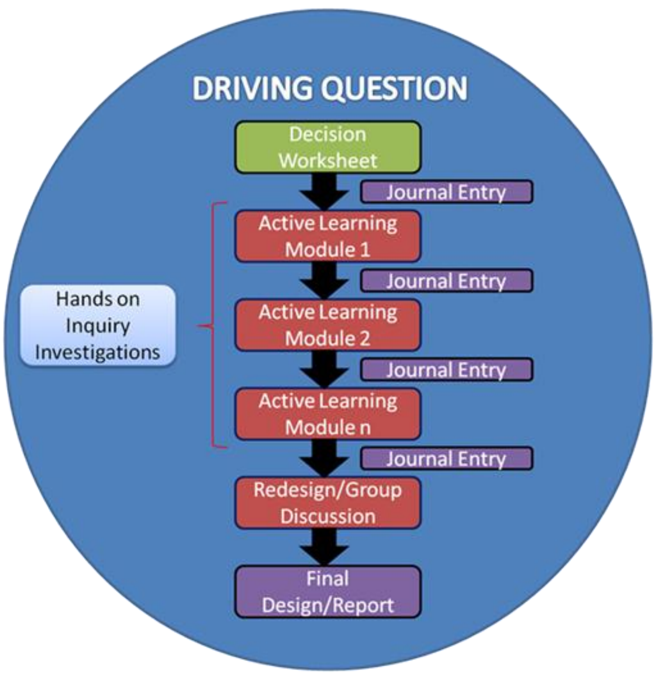

FIGURE 1
INSTRUCTIONAL FLOWCHART FOR EFFECTS.

Hands-on investigations are inquiry-based and sufficiently open-ended to allow students to explore and test their prior (mis)conceptions and to assume ownership of the resulting outcomes. In this way, students can make self-discoveries of a concept, equation, theorem, or other piece of knowledge needed for the driving question. For example, hands-on activities in geotechnical engineering guide students to learn about weight-volume relationships for soil and the influence of soil type, compaction, and water

Context:
Most people think of structures as being built of concrete, steel, or wood. Earthen materials are also used for a number of different civil structures, such as road embankments, walls, dams and levees. A levee can be defined as "an embankment designed to prevent the flooding of a river." When Hurricane Katrina hit the city of New Orleans in August 2005, portions of the levee system collapsed, allowing water to flood the streets, businesses and homes across the city. Your engineering firm has been selected to reconstruct an earthen levee section in New Orleans. It is anticipated that the water can rise 30 ft. above its normal level during the storm surge from a Category 3 hurricane. Concrete panels are also built on top of the levees to help extend the height of the protection system.

Driving Question:
How many tons of soil do you need to build each 100-ft. long section of levee?

Guiding Questions:
1. Sketch the detailed shape of the levee with appropriate dimensions (in feet) and angles (in degrees). Explain how and why the shape and measurements were selected.
2. What do you need to know to make an accurate estimate of soil weight? Why? List as many items or factors that you think are important for an accurate estimation.
3. Estimate a value for each item or factor listed in part b (for those items or factors that require some known quantity). What is your level of confidence about each estimated value, and why?
4. A levee can fail in different ways. What would you consider failure of the rebuilt levee section? Why?

FIGURE 2
DECISION WORKSHEET FOR GEOTECHNICAL EFFECT.

content on soil density. Using this knowledge, students construct physical models of a levee as part of the last active learning module. The models are subjected to canal flooding, and the students observe the performance of each model levee over several days. It is not uncommon for the model levees to fail due to erosion, sliding, or excessive seepage. Active learning topics for other EFFECTs can be found in Pierce et al. [12].

After each class in which students engage in hands-on activities, they reflect on their experimental outcomes via online journal entries. Effective writing prompts for journal entries must be open-ended and mechanistic, as well as specific enough to draw out each student's knowledge while still encouraging critical thinking. To this end, journals solicit responses to three important questions: 1) *what* was learned; 2) *why* that core knowledge is important in the context of the driving question; and 3) *how* that core knowledge has altered the original solution to the driving question. Journal entries form the basis for students to gain an awareness of, and practice in, the recursive problem-solving process used in engineering.

A critical thinking rubric was developed to evaluate the written assignments used in EFFECTs [12]. This rubric provides a dual assessment of core knowledge and critical thinking, as shown in Figure 3. A detailed description of the assessment levels and rater reliability data can be found in Pierce et al. [12]. It has been used primarily to evaluate journal entries, although it can be applied to the decision worksheets and final reports. Prior to the first journal

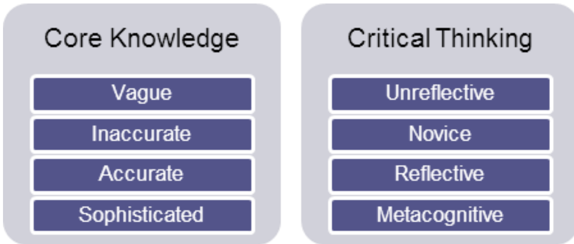

FIGURE 3
CRITICAL THINKING RUBRIC FOR EFFECTS.

entries, the rubric is distributed and discussed in class. Students are expected to submit journal entries that are accurate and reflective; full credit is earned for achieving both levels. Here, accurate core knowledge is defined as using *"several specific terms and the majority of them accurately."* Reflective critical thinking is defined as using *"multiple observations to draw a conclusion"* where the *"majority of reasoning must be valid."* A reflective response should also make *"new connections among topics within the course."* Journal scores are reduced if these levels are not met, and extra credit is given for submitting sophisticated and/or metacognitive responses.

STUDENT PERCEPTIONS OF ECIV 101

At the end of the course, students completed the required student evaluation forms and a course-specific questionnaire. Hands-on activities and in-class interaction, both at the instructor-student and peer-peer levels, were the most frequently cited positive aspects of the course, according to results compiled from student evaluation forms. Students also recognized the contextual importance of these activities, with comments indicating the design scenarios provided *"meaningful projects"* that *"helped me to understand engineering"* and offered insight on *"what I wanted to do"* as a civil engineer. The writing assignments associated with each project were identified as the most challenging aspects of the course. Students suggested having fewer journal questions and desired more help from the instructors with the final reports.

The course-specific questionnaire is divided into two sections, one to evaluate the introduction to civil engineering and one to evaluate the EFFECTs components. Overall, students like this course and perceive it to be a favorable introduction to the discipline. Student responses to the following statements are consistently high on a Likert scale from 1 to 5, where 5 indicates Strongly Agree.

- *This class gave me a better appreciation for civil engineering*: annual ratings ranging from 4.0 to 4.6, with a five-year mean rating of 4.3;
- *I like the method of learning used in this course compared to other science and engineering classes*: 3.9 to 4.5, with a mean rating of 4.3; and
- *Technical concepts taught using the methods in this class were easier to understand than in traditional classes*: 4.0 to 4.3, with a mean rating of 4.2.

Table II summarizes student responses to three questions on each of the civil engineering distribution areas that were introduced through EFFECTs during that particular semester. The three questions are:

1. Interest Level: Are you interested in [x] engineering?
2. Hands-on Experiences: Did you find the hands-on activities interesting for [x] engineering?
3. Learning Level: Did you learn a lot about [x] engineering?

Here, [x] represents environmental (E), geotechnical (G), structural (S), transportation (T), and water resources (W). The available responses to each question were Yes (assigned a value of 3), Neutral (2), and No (1). The results shown in Table II represent the mean response calculated over the five-year period from 2007 to 2011. Question 1 on Interest Level was included each semester for all five distribution areas, regardless of whether or not students were exposed to that area through EFFECTs. Each semester, students answered Questions 2 and 3 for the specific areas that were covered using EFFECTs. Geotechnical engineering is the only area that has been covered each one of the five years; transportation engineering, on the other hand, has only been taught once (see Table I).

TABLE II
STUDENT ASSESSMENT OF EXPOSURE TO CIVIL ENGINEERING DISTRIBUTION AREAS

Survey Question	Five-Year Mean Class Response [3.0 scale]				
	E	G	S	T	W
Interest Level	1.9	2.6	2.9	2.0	1.8
Hands-on Experiences	2.3	3.0	3.0	2.2	2.4
Learning Level	2.6	2.9	2.9	2.9	2.7

From Table II, it is clear that first-year students tend to gravitate toward the geotechnical and structural engineering fields. Those two fields consistently rate the highest in student interest and hands-on experiences. In all cases, the mean ratings for hands-on experiences are higher than the student interest level. This finding suggests that students appreciate being engaged in the classroom, even if the topic is not of the greatest interest. Most importantly, the mean ratings for the students' perceived learning surpasses 2.6 on a 3.0 scale in all five areas. This finding is somewhat surprising but promising, given the lower levels of interest in three of the five areas. It also implies that the EFFECT framework for teaching and learning is successful in this course.

A more explicit illustration of the successful implementation of EFFECTs is shown in Table III, which summarizes student responses to questions about individual components of the EFFECT framework. Here, students were asked to rate, on a Likert scale from 1 to 5, the importance of each component with 1) helping them answer the driving question and 2) helping them develop their critical thinking skills. Results shown in Table III represent the mean response calculated over the five-year period from 2007 to 2011.

TABLE III
STUDENT ASSESSMENT OF EFFECTS COMPONENTS

EFFECT Components	Five-Year Mean Class Response [5.0 scale]	
	Helped Answer Driving Question	Helped Develop Critical Thinking
Decision Worksheet	4.0	3.8
Group Discussions	4.5	4.1
Hands-on Experiences	4.8	4.6
Journal Entries	3.5	3.5
Final Reports	---	4.2
Faculty Guidance	4.6	---

It is evident that hands-on experiences are the most impactful in terms of answering the driving question and development of critical thinking. Journal entries, on the other hand, do not resonate as much as the other components, although the mean ratings of 3.5 are still somewhat positive (between Neutral and Agree). In a separate question, however, most students indicated that they were unlikely to refer back to their journal entries, including the instructor feedback on student responses, when preparing the final report. In terms of critical thinking, students believe that writing the final report is also a significant contributing factor. In terms of the driving question, students believe that faculty guidance was significant in helping them devise an appropriate solution. This finding supports other anecdotal evidence that students appreciated the engagement of instructors in a highly interactive learning environment.

IMPACTS OF ECIV 101 ON SOPHOMORE RETENTION

The sophomore retention of first-year civil engineering students is shown in Table IV. Data were compiled for three consecutive academic years beginning with the Fall 2008 semester. The total number of first-year civil engineering students is divided into two groups: 1) students enrolled in ECIV 101 and 2) students not enrolled in ECIV 101. As shown in Table IV, about two-thirds to three-quarters of first-year students do not enroll in ECIV 101. The vast majority of those students enrolled in ECIV 111, although a small number of students enrolled in Introduction to Engineering (ENCP 101) or Introduction to University (UNIV 101) instead. Neither ENCP 101 nor UNIV 101 counts for credit in the civil engineering curriculum, so the number of first-year students in those two courses is normally low.

The total number of sophomores is also divided into two groups: 1) students that continued in civil engineering and 2) students that transferred to another major. The total number of sophomores does not include students who left the university or conditional students. Students with a grade point average below 2.0 are considered conditional and are not allowed to declare a major. The percentage of retained students and transferred students shown in Table IV are based on the number of returning sophomores, not the number of first-year students.

Table IV shows the sophomore retention rate in civil engineering is higher for students that complete ECIV 101. Approximately 80% of ECIV 101 students returning as sophomores remain declared in civil engineering, which is higher than the 67% retention rate for non ECIV 101 students. This means that a higher percentage of sophomores in good academic standing decided to transfer out of civil engineering if those students had not completed ECIV 101. To put that in context, 40 of 123 (33%) non ECIV 101 students transferred out of civil engineering. Based on the lower transfer rate (19%) for ECIV 101 students, it is projected that 23 of the same 123 students would have transferred, which equates to a potential net gain of 17 students in the major during that three-year period. It should be noted that no distinction was made between students who transferred within the College of Engineering and Computing and those who transferred to another college within the university. Based on anecdotal comments from some ECIV 101 students, however, the course reinforced their decision to continue with an engineering education, but pursue an alternative major.

TABLE IV
PERSISTENCE OF FIRST-YEAR CIVIL ENGINEERING STUDENTS

First Civil Engineering Course	First-Year Civil Engineering Students [no.]	No. of Students Returning Sophomore Year in Good Academic Standing (GPA > 2.0)			
		Major in Civil Engineering		Transfer to New Major	
		[no.]	[%]	[no.]	[%]
Fall 2008					
ECIV 101	24	15	79%	4	21%
Non ECIV 101	49	22	65%	12	35%
Fall 2009					
ECIV 101	24	13	81%	3	19%
Non ECIV 101	57	29	66%	15	34%
Fall 2010					
ECIV 101	17	11	85%	2	15%
Non ECIV 101	54	32	71%	13	29%
Three-Year Totals					
ECIV 101	65	39	81%	9	19%
Non ECIV 101	160	83	67%	40	33%

The comparisons drawn between ECIV 101 and non ECIV 101 students assume the two groups can be considered as treatment (ECIV 101) and control (non ECIV 101) groups, meaning that there is acceptable group equivalence. It should be noted that student self-selection of ECIV 101 is impeded by the advisement process for first-year students, which mitigates the potential differences between the two populations. During the summer orientation sessions, first-year students are advised to enroll in ECIV 111 because it is a required course. ECIV 111 is taught in a computer lab with limited seats, and the maximum capacity is normally reached before the last summer orientation sessions are held. At that time, students are advised to enroll in ECIV 101. Students who do not attend summer orientation, and therefore register late, are also advised to enroll in ECIV 101. As a result of the advisement process, there is some randomness in the student assignments within the two student groups.

While ECIV 101 has a measurable influence on persistence within the major, it does not appear to have changed the total rate of return to the institution. During the three-year evaluation period, 74% (48 of 65) ECIV 101 students returned as sophomores in good academic standing, which is slightly less than the 77% (123 of 160) non ECIV 101 students. ECIV 101 is intended to provide first-year students with the tools for succeeding in a rigorous academic environment. It does not necessarily serve as support for the transition from high school or the management of social and economic challenges associated with that transition. Given that students withdraw from an institution for a multitude of different reasons, it is not surprising that the institutional persistence rate is not impacted by this particular course.

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