AC 2009-1341: ASSESSMENT OF ENVIRONMENTS FOR FOSTERING EFFECTIVE CRITICAL THINKING (EFFECTS) ON A FIRST-YEAR CIVIL ENGINEERING COURSE

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Abstract

The Environments For Fostering Effective Critical Thinking (EFFECTs) are modular inquiry based tools specifically designed to develop critical thinking skills and collaborative teamwork skills and to improve the transfer of core knowledge in engineering classes. Student capacity for making reasonable estimates, or ballparking, is also developed in this framework. EFFECTs are based on a driving question where students work in the context of a realistic civil engineering project. Each driving question is followed up with hands on activities to enhance the student's core knowledge, stimulate critical thinking, and perfect their estimation abilities. EFFECTs have been implemented at three different institutions for two years.

This paper discusses the implementation of EFFECTs and assessment techniques in a first-year course for undergraduate civil engineering students. Four data sources are used to measure the development of students' critical thinking skills and estimation abilities. These include: i) a pre-post written test of both core knowledge and fundamental skills, ii) open-ended, written decision worksheets responding to each EFFECT's driving question, iii) journal entries, and iv) student evaluation of the class. This paper focuses on the implementation of the EFFECTs and assessment techniques. In particular, the use of an online driven database to fast-track the assessment of critical thinking and core knowledge during the EFFECTs

Introduction

Engineering judgment is generally regarded as critical to success in an engineering career. However, engineering judgment is not a tangible concept with clearly defined components or procedures that can be easily taught. Good engineering judgment is fostered and developed by engineers after years of experience. Similar to the role that content knowledge and experience play in scientific reasoning (i.e., reasoning skills are not context independent)[1,2], engineers use core knowledge, draw upon previous authentic experiences, and use fundamental technical skills to arrive at a solution (e.g., a design or analysis of the problem at hand). Engineering judgment goes beyond the development of a solution and is a product of critical thinking regarding the appropriateness of the solution.

Engineering colleges and instructors have as a common goal that students be able to formulate good engineering judgment at the end of a course[3]. Currently, most classes provide students with core knowledge and technical skills within the curriculum. Students in the classroom are extensively exposed to the process of generating a solution. Instructors frequently evaluate students on the basis of whether the solution is "correct" and if they properly followed a process. Obtaining the correct solution does not constitute engineering judgment until the student has critically thought about the solution. The appropriate level of thinking ranges from the very basic (e.g., If determining the height of a column in a building, should the solution be reported with 8 significant digits?) to the more complex (e.g., Will the building be able to withstand an

earthquake of a specific magnitude?). Thus, students who are given more opportunities to think critically about a solution would develop a better sense for formulating engineering judgment. Educating students to be critical thinkers becomes a key aspect in the success of educating good engineers.

This paper presents the Environments For Fostering Effective Critical Thinking (EFFECTs) and how this educational approach has been implemented and managed within an Introduction to Civil Engineering course. The paper describes a rubric specifically designed to measure core knowledge and critical thinking for questions posed within an engineering context and an Online Assessment Tool (OAT) used to streamline the assessment process.

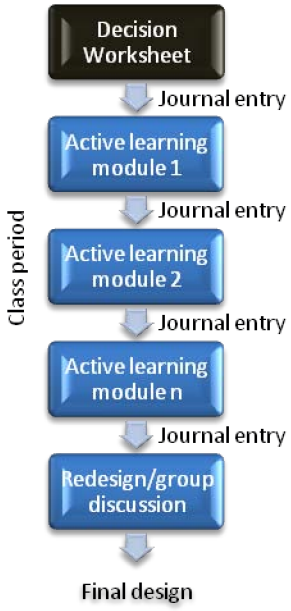

Figure 1. EFFECTs pedagogical structure.

EFFECTs pedagogical strategy

Each EFFECT follows the same pedagogical structure shown in Figure 1, which provides students with a repeatable and recognizable atmosphere to stimulate critical thinking. The EFFECT structure contains three elements: 1) a decision worksheet that guides an initial design during the first class period, 2) active learning modules and journal questions during the next *n* class periods, and 3) group discussion during the final class period that guides a final design. The decision worksheet presents students with a design problem framed in a specific context, like those in Table 1, and it aids the thought process for identification of the important factors that will govern design. Students must also provide supporting justification for why they think those factors are important. After completing an individual worksheet, students form groups to discuss their designs and debate design assumptions, benefits and possible weaknesses. Each group then presents its consensual design, which other groups critique within a supportive environment that encourages conceptual change and meaningful learning for each student. Each driving question is based on realistic scenarios that students can relate to without technical knowledge, but is broad enough that it can be used to teach significant content in an advanced engineering course. Figure 2 shows the decision worksheet used in the first day of class of the environmental engineering EFFECT. The goal of this EFFECT is to design an activated carbon filter for water treatment. Students answer all questions individually and with their design team during the first day of the EFFECTs. The misconceptions and answers to these questions provide a springboard for the active learning activities on the subsequent days of the EFFECTs.

A well-designed driving question must be supported with a series of interchangeable active learning modules that address fundamental concepts. Feasibility of the initial design solution is studied during the active learning modules by discussing or testing some of their design assumptions. Active learning modules can include active demonstrations, hands-on experimentation and data acquisition, interactive lectures using classroom response systems (or clickers), in-class writing exercises, classroom debates, computer simulations, or case studies. For example, an EFFECT was created for the driving question, "How much soil is needed to re-construct a 100-ft. long section of earthen levee in New Orleans?" At the freshman level, this

EFFECT has three active learning modules designed for students to explore soil composition and fundamental mass-volume relationships for different soils through hands-on experimentation. The sequence concludes with students constructing and testing a model levee based on their own design.

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

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Environmental Engineering

Figure 1. Aerial view of a water treatment plant. From http://civil.engr.siu.edu/Ray_H2ODsn/images/WTPAerial1.jpg

Civil engineers design water, wastewater, and groundwater treatment systems to purify water prior to consumption or discharge into a receiving body of water. Treatment systems contain numerous processes to achieve a desired final water quality. Examples of these processes include particulate removal by gravity settling and filtration, biological treatment to degrade organic compounds, and disinfection. Activated carbon (AC) is a material that can be used to remove a wide array of organic contaminants and can also remove low levels of heavy metals. AC works by adsorbing contaminants from solution, i.e., transferring contaminants from the liquid phase to the solid phase (on the surface of the AC). AC has surface areas ranging from several hundred to a few thousand m^2 per gram of AC. A large surface area indicates that the AC could potentially remove a significant amount of contaminants.

As an engineer, you are asked to design a water treatment system for a small community that includes an activated carbon filter. What are the dimensions of the activated carbon filter?

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?**

Figure 2. Environmental engineering decision worksheet

this new knowledge has impacted or changed their initial design. With this directed journaling, a habit of revisiting their design is created, which encourages students to think critically about their design and to improve it based on new concepts. The journal entries and decision worksheets are of particular importance to assess each student's critical thinking and core knowledge. Figure 3 shows two sample journal entries. The first one is for the structural engineering EFFECT and the second one is for the geotechnical engineering EFFECT. The structural engineering entry was performed after the first day of class, while the Geotechnical engineering entry was performed after one of the active learning meetings (3rd day of the EFFECT).

Table 1. Current EFFECTs

EFFECT	Context and driving question	Active learning modules
Surveying	A parking lot is to be paved. What is the area of parking lot that should be used to calculate the volume of concrete?	• Estimation and measurement of areas with small, regular shapes and large, irregular areas
Environmental Engineering	A water filtration system is to be developed using activated carbon. What are the dimensions of the activated carbon filter?	• Concentration and calibration • Material balance
Transportation Engineering	A hurricane is rapidly approaching a coastal city. How much time is required for safe evacuation?	• Traffic flow • Traffic density
Water Resources	A water tower is to be designed for a new subdivision. How tall should the water tower be?	• Static water pressure • Bernoulli principle
Geotechnical Engineering	A 100-ft long section of earthen levee is to be reconstructed. What weight of soil is needed?	• Material density • Soil composition and compaction
Structural Engineering	A water tower is to be built in a seismic region. What shape of the supporting structure is needed to avoid its collapse during an earthquake?	• Stiffness and moment of inertia. • Dynamic characteristics of structures (natural frequencies and mode shapes)

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.

Six EFFECTs were developed and implemented at the University of South Carolina, Midlands Technical College and Marshall University as shown in Table 1. This table also shows the context of the driving question and the active learning modules that have been developed for each EFFECT. All six EFFECTs were implemented in the Introduction to Civil Engineering class at the University of South Carolina during the first year. Four EFFECTs (surveying, water resources, geotechnical and structural engineering) were used during the second year based on student feedback received during the first year. The feedback indicated that Six EFFECTs were too many EFFECTs for one course and probably the maximum the number of EFFECTs in one class should be limited to four or five. Three faculty members and one TA taught the EFFECTs at USC. The TA worked mostly in evaluating journal entries (with the faculty) and organizing the data collected from the students in the database. It is possible that one instructor can successfully implement the EFFECTs in this class without the need of being expert in the subject area as shown on the implementations at Midlands Technical College. The structural engineering and the surveying EFFECTs were implemented at the structural design and

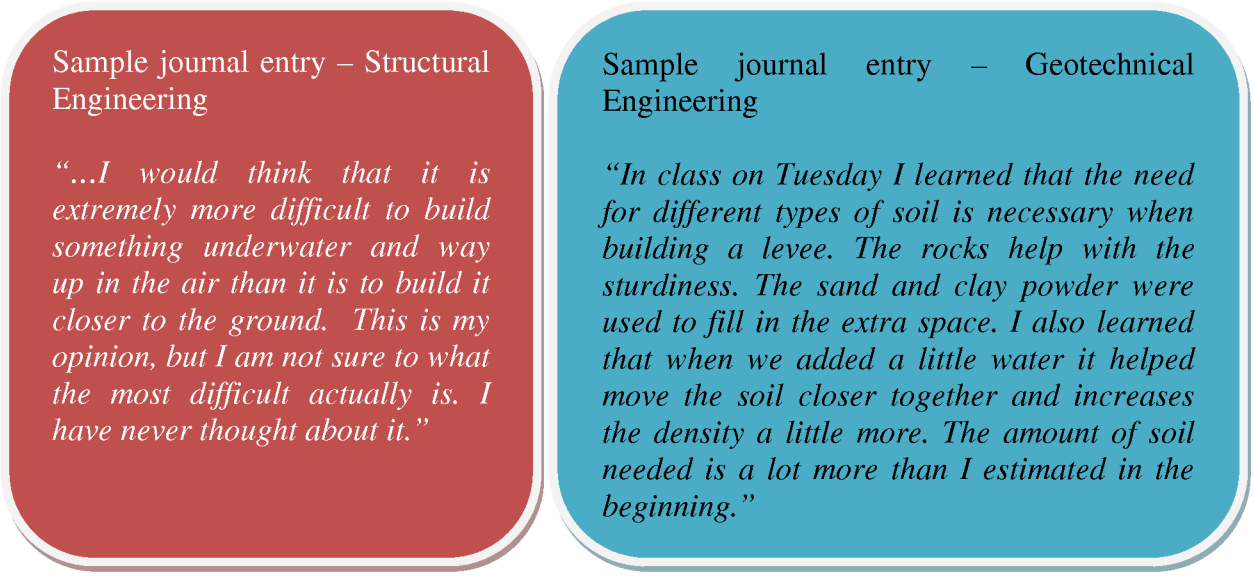

Figure 3. Sample Journal Entries

surveying classes at Midlands Technical College, and the Transportation EFFECT was implemented in the Introduction to Civil Engineering at Marshall University. Only one faculty member was responsible for the classes at MT and MU.

We are currently following students as they progress through the curriculum and evaluating their performance at different classes using pre and post tests. In addition, we are evaluating the senior design projects for evidence of critical thinking and core knowledge. This longitudinal study will allow us to know the outcomes of the EFFECTs on student's critical thinking and learning.

PROJECT ONLINE ASSESSMENT TOOL (OAT)

An Online Assessment Tool (OAT) was developed to facilitate the assessment process. OAT is web-based and it can be accessed by multiple users simultaneously. OAT has been used to collect and evaluate journal entries and decision worksheets. OAT has been fully implemented at USC and partially implemented at MT and MU. The full implementation of OAT has four main modules: 1) student, 2) hard copy upload, 3) coding and 4) metrics modules. The student module allows students to enter journal responses and receive feedback as soon as the faculty (or TA) has rated their journal entries. Students would access a web page and type their journal entries on a specific journal entry. The entry was immediately accessible to the instructor for evaluation. This is important because students are asked to review their journals and feedback before writing the final report, encouraging the re-evaluation of their ideas and designs. The hard copy upload module allows the addition of material written in paper form to OAT and it is currently used for the decision worksheets. A fast double side scanner was brought to class and student's paper copies were scanned in class. This method was found to work very well and did not provide any interruption to the class flow. The images were uploaded later into a program that would crop each answer and upload them directly to the database. The coding module allows faculty and TAs to quickly rate journal entries and decision worksheets. Figure 4 shows a snap

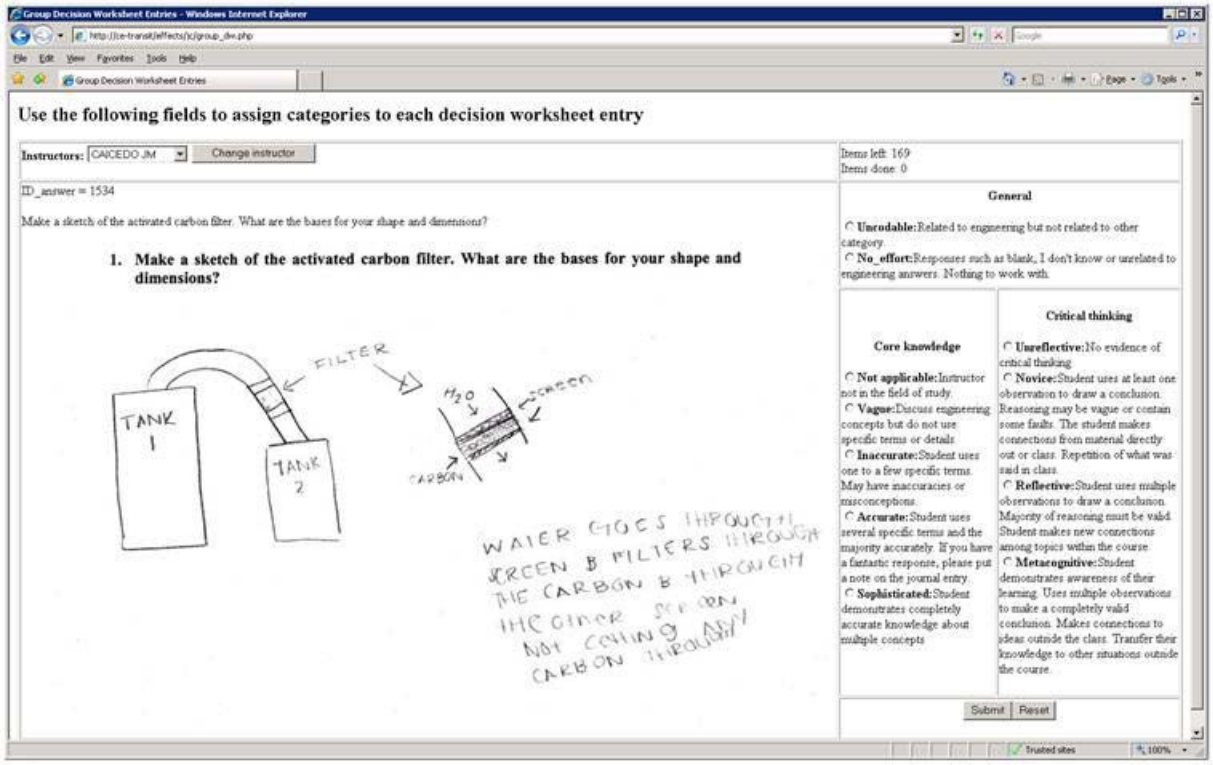

Figure 4. Coding Module - Online Assessment Tool

shot of this module. Faculty and TAs are required to add an explanation of their review, including comments about how students can improve their journal entries. The metrics module is used to calculate inter- and intra-rater reliability and it can display different data views (e.g., average and standard deviation of journal entries for each EFFECT per class, average of scores per student in a particular EFFECT, etc.). More information about the intra-inter reliability can be found in the results section of this paper. Project evaluators have direct access to the OAT database and can query it for more assessment information directly. Currently, OAT has over 500 journal entries and more than 2000 evaluations of these journal entries (some have been coded more than once to measure rater reliability). OAT also has over 500 entries for decision worksheet questions and over 1300 decision worksheet ratings.

Critical thinking rubric

A rubric used to code journal entries and decision worksheets was developed. Meaningful engineering judgment is based on core knowledge and critical thinking skills. The rubric reflects the importance of both by independently rating each one into one of four different categories (Table 2).

Table 2. 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.

Results

Intra- and inter-rater reliability was calculated using a GENOVA analysis[4,5] of coded journal entries using this rubric (Table 3). Data were used from seven raters, including five engineering faculty members from three institutions, one science faculty member, and one engineering graduate student. The first number in each cell corresponds to core knowledge and the second to critical thinking. The smallest reliability was 0.67, with most numbers over 0.75, which makes the rubric reliable[6]. The average number of samples for the reliability calculations is 21; the minimum is 12 and the maximum is 46.

Table 3. Intra/Inter-Rater Reliability (Core Knowledge, Critical Thinking)

Rater	1	2	3	4	5	6	7
1	0.90, 0.89	0.84, 0.82	0.87, 0.60	0.87, 0.91	0.91, 0.92	0.88, 0.88	0.94, 0.91
2		0.76, 0.86	0.68, 0.93	0.74, 0.82	0.78, 0.91	0.68, 0.85	0.93, 0.95
3			0.79, 0.75	0.71, 0.87	0.95, 0.93	0.70, 0.94	0.84, 0.88
4				0.91, 0.96	0.91, 0.88	0.62, 0.70	0.94, 0.91
5					0.87, 0.91	0.67, 0.90	0.96, 0.91
6						0.78, 0.84	0.94, 0.92
7							0.77, 0.68

The Online Assessment Tool showed to be successful in allowing faculty to evaluate journal entries within the EFFECTs pedagogical model in the introduction to civil engineering at USC. In addition, students were able to obtain feedback faster than using paper based journals, creating a more meaningful feedback system for students because it provides the rating (e.g. grade) and rating justification. The EFFECTs were taught during the Fall of 2007 without the use of OAT and during the Fall of 2008 with the use of OAT. When students from the 2007 class were asked to rate how helpful was the feedback from faculty given on the journal entries the mean score was 3.4 on a 5 point scale (1 being not helpful at all and 5 being very helpful). In contrast, students in the 2008 class rated the faculty feedback on journal entries as 4.0. In addition, students rated how important the journal entries were for their development of critical thinking skills. First year students gave a mean score of 3.1 while students participating during the

second year gave an average score of 3.8. Journal entries were also more helpful to solve the driving question during the second year (3.9/5.0) than during the first year (3.3/5.0).

Conclusions

This paper presents the Environments For Fostering Effective Critical Thinking (EFFECTs). In particular, the pedagogical structure, and the rubric used to evaluate critical thinking and core knowledge in student's journal entries is discussed. This pedagogical structure has been successfully transferred between two year and four year institutions, and we believe that it can be implemented in other institutions. A key aspect in the development of the EFFECTs was the design of the driving question, and decision worksheet. The context given by the decision worksheet has to be in accordance to the class being taught. In an introductory class the context will constrain the particular problem, while in an advanced class the context will be more flexible. In the other hand, we found that good driving questions should incorporate several aspects of a design or analysis. For example, the geotechnical engineering driving question is to find the weight of the soil needed to design a 100 foot levee. This requires the student to consider the type of soli to use, the geometry of the earth structure, water pressure, etc. A complete course in geotechnical engineering could be taught using this driving question. The research team is currently developing EFFECTs handbooks containing the necessary information to help other instructors implement this material in their classes, or to develop their own EFFECTs. Instructors can decide to add new active learning classes, or not use some of the active learning material for a particular EFFECT based on the time available for the class, or the specific topics to be covered. Common misconceptions and typical results from active learning modules will be incorporated in the EFFECTs handbooks.

The critical thinking rubric was found to be reliable as shown in the results section of the paper. In addition, the rubric was very easy to implement by faculty and TAs. Although the use of the Online Assessment System facilitates the implementation of the rubric, it is not required for the implementation of the EFFECTs. Journal entries can be collected on paper, and the instructor or TA can grade the journal entries using the critical thinking rubric. The instructors found that it was important to share the rubric with students before their first assignment. In addition, feedback from instructors is more meaningful when the instructors mention the specific items of the rubric and explain the student deserves a specific grade in terms of the rubric items.

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