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Using Engineering Problems to Stimulate Critical Thinking in the Middle School Science Classroom (works in progress or curriculum exchange)

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Introduction

Pedagogical approaches that help develop critical thinking skills at all academic levels are prominent in the national education discourse. Research shows that active learning is one approach that stimulates critical thinking. When students are actively engaged in the classroom, the academic environment is elevated and student learning can be improved. Students are even more engaged and connected to the subject when content is relevant and meaningful. The Department of Civil & Environmental Engineering at the University of South Carolina and a local school, Beaufort Middle School, have forged an educational partnership aimed at developing and implementing problem-based hands-on activities that can be incorporated within middle school science classes to 1) enhance student learning, 2) increase critical thinking and problem solving skills, and 3) raise student and teacher awareness of engineering issues and careers. The goal of this paper is to discuss this partnership and the transfer of a pedagogical approach, called EFFECTs, from the collegiate engineering environment to middle school science.

What are EFFECTs?

The Environments for Fostering Effective Critical Thinking, or EFFECTs, are modular inquiry based tools designed to stimulate critical thinking and collaborative teamwork while improving the transfer of core knowledge in engineering.[1] The pedagogical framework for EFFECTs links two critical elements, active learning and reflective writing, within the context of a realistic engineering design problem. Lipman[2] 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."* The EFFECT framework is designed on the basis of this definition.

EFFECTs begin with a driving question that is embedded in a decision worksheet, which students complete, individually and then in groups, to provide an initial answer to the driving question. The decision worksheet is followed with multiple active learning sessions that are designed to enhance core knowledge, stimulate critical thinking, and hone estimation abilities. Students reflect on their learning by responding to journal questions after each active learning session, and instructors evaluate student responses using a rubric designed to assess both core knowledge and critical thinking. Journaling provides opportunities to revise answers to the driving question based on new knowledge, and it facilitates the identification of student misconceptions or misunderstandings. Each EFFECT concludes with a student-generated document, such as a report, that contains a final answer to the driving question and a description of how the solution changed as a result of the active learning exercises. Engineering EFFECTs have been developed and implemented at all academic levels in higher education, from first-year courses[3] to graduate courses. Detailed examples of EFFECTs can be found for water filtration[4] and solar power for a rest area.[5]

University-Middle School Partnership

The educational partnership described herein is based on a six-step model that was developed to guide the transfer of EFFECTs to the K-12 environment, as follows:

Step 1: Guest Instruction – an engineering faculty member develops and presents a modified EFFECT in a science class while the science teachers observe and/or participate;
Step 2: Training Workshop – engineering faculty members conduct a professional development workshop for teachers to draft EFFECTs appropriate for their particular grade level;
Step 3: Mentor-Mentee Relationships – an engineering faculty member partners with a science teacher to help refine the EFFECTs prior to implementation;
Step 4: Community of Practice – an online forum is created for the exchange of ideas, challenges, and questions among the teachers and engineering faculty members;
Step 5: Implementation and Evaluation – teachers implement their developed EFFECTs and share observations, concerns and challenges with mentors (Step 3) and the greater community of practice (Step 4), with the intent of making appropriate revisions leading to a high-quality publication (see Step 6); and
Step 6: Dissemination – mentors and mentees collaborate to publish each EFFECT, using a pre-developed template, in appropriate venues such as the TeachEngineering digital library.

The current partnership between the University of South Carolina and Beaufort Middle School has advanced through Steps 1 and 2, and Steps 3 through 5 are in various stages of progress as described below.

Step 1: Guest Instruction
In 2010, an environmental engineering EFFECT was designed and implemented in two different 6th grade science classes at Beaufort Middle School. Through cooperation with the local science teachers, the EFFECT was revised and taught again in 2011 and 2012. In this EFFECT, students learn about what environmental engineers do, including their responsibilities for providing communities with clean and safe drinking water. Students complete a decision worksheet and then are assigned to groups of acting environmental engineers, where each group must design and construct a filtration system for a water treatment plant. Groups "purchase" materials (activated carbon, cotton, gravel and sand) within a fixed budget and explore how these materials absorb and filter a contaminated water source (simulated with red food coloring in the water). Each group redesigns their filter and competes with other groups to see which one produces the "safest" water. Each student completes a final decision worksheet to assess his/her acquisition of knowledge and ability to think critically about the design.

Step 2: Training Workshop
A full day EFFECTs Workshop was conducted with all seven science teachers at Beaufort Middle School in September 2012. This workshop was modeled after the First (2011) and Second (2012) Annual EFFECTs Workshops that were conducted on the campuses of the University of South Carolina and Marshall University, respectively, for engineering faculty members. The workshop content was modified to be more appropriate for middle school teachers; the agenda is shown in Figure 1. Detailed presentations that compared the water filtration EFFECT at the undergraduate engineering level to the one described above in Step 1 for middle school proved to be important elements of the workshop. The workshop was successful and generated positive response from the science teachers.

Most importantly, four EFFECTs were conceptualized and initial drafts of decision worksheets and active learning modules were created during the workshop. All of these EFFECTs were trial tested during the fall 2012 term, and are in the process of being evaluated and revised (see Steps 3 and 4 below). The EFFECTs include: 1) Christmas Parade – should it be rescheduled based on the weather forecast?; 2) Newton Scooter – what is the impact of design on its motion?; 3) Ace Basin Research Reserve; and 4) Beach Bash 2012.

I. NSF EFFECTs Project Overview

II. Workshop Goals: What is an EFFECT?

III. Functional Framework: Demonstration of Example EFFECT in Environmental Engineering

IV. Developmental Framework: Discussion of Transferring EFFECTs to Middle School and Interactive Working Session to Develop Draft EFFECTs

V. How to Evaluate EFFECTs

VI. Workshop Evaluation

Figure 1. EFFECT Workshop Agenda

Steps 3 and 4: Mentor-Mentee Relationships and Community of Practice
These components of the University-Middle School partnership are on going. Mentor-mentee relationships have been established (with the authors of this paper serving as mentors) and a community of practice has been initiated via the development of an online group using Edmodo. This group provides the science teachers with access to engineering faculty and has become a valuable platform for discussion on the development and implementation of EFFECTs.

Step 5: Implementation and Evaluation
Teachers have shared their experiences with implementing EFFECTs through an online survey and a focus group discussion held in January 2013. One of the outcomes of the focus group was the need for a follow-up workshop, which is being planned for teachers to interact with engineering faculty and revise/refine their EFFECTs.

Conclusions to Date

The EFFECT framework has been well received by the Beaufort Middle School teachers. Based on a focus group discussion with the science teachers, specific aspects of these activities that were considered to be the most beneficial include: student engagement and collaboration; evaluation of real-world problems; sequencing of topics to demonstrate interrelationships; and genuine student interest in the activities.

References

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