International Journal of Engineering Education Vol. 30, No. 6(B), pp. 1579–1589, 2014
Printed in Great Britain

0949-149X/91 $3.00+0.00

Integrating Professional and Technical Engineering Skills with the EFFECTs Pedagogical Framework*

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This paper describes the Environments for Fostering Effective Critical Thinking (EFFECTs) pedagogical framework that has been developed and implemented across the civil and environmental engineering curriculum at the University of South Carolina. Thirteen unique EFFECTs have been created to date, impacting seven different courses. This instructional approach has been used in courses at all undergraduate levels, from first-year introduction courses to upper division elective courses. The cumulative application of EFFECTs facilitates the integration of technical and professional skills to meet programmatic student outcomes. This paper provides a map of the ABET and ASCE student outcomes that are addressed with EFFECTs, with appropriate examples from different EFFECTs modules. In terms of professional student outcomes, the EFFECTs framework is designed to enhance student communication skills, teamwork, and knowledge of contemporary issues. In addition to these three core outcomes, each EFFECT can incorporate other professional skills, depending on the nature and content of that particular EFFECT. The implementation of EFFECTs has reached a point where most, but not all, upper division students (seniors) have been exposed to the EFFECT approach at least once during their academic program. Survey results on student self-perceptions of professional skill development are reported in this paper. Based on those findings, teamwork is the highest rated outcome. Professional skill development was also found to improve significantly when students are exposed to EFFECTs in more than one course.

Keywords: ABET; ASCE; civil engineering; communication; contemporary issues; critical thinking; professional skills; student outcomes; teamwork

1. Introduction

Professional development has long been recognized as a critical, but often lacking, component in engineering education. As undergraduate engineering degree programs continue to move towards a more rigorous outcomes-based assessment, there are opportunities to create and implement innovative strategies for the integration of teaching and learning that meets both technical and professional outcomes. In the U.S., the Accreditation Board for Engineering and Technology (ABET) is the leading organization for the development and programmatic assessment of engineering student outcomes. ABET General Criterion 3 establishes eleven student outcomes [1], designated (a) through (k), as follows: (a) an ability to apply knowledge of mathematics, science, and engineering; (b) an ability to design and conduct experiments, as well as to analyze and interpret data; (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; (d) an ability to function on multidisciplinary teams; (e) an ability to identify, formulate, and solve engineering problems; (f) an understanding of professional and ethical responsibility; (g) an ability to communicate effectively; (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; (i) a recognition of the need for, and an ability to engage in life-long learning; (j) a knowledge of contemporary issues; and (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

In the field of civil engineering, the American Society of Civil Engineers (ASCE) provides guidance for discipline-specific expectations for student outcomes in its *Civil Engineering Body of Knowledge (BOK) for the 21st Century* [2]. The BOK identifies 24 learning outcomes, divided into foundational, technical, and professional outcomes. The nine professional outcomes are: (16) communication, (17) public policy, (18) business and public administration, (19) globalization, (20) leadership, (21) teamwork, (22) attitudes, (23) lifelong learning and (24) professional and ethical responsibility. There is considerable overlap between the ABET and ASCE expectations for professional develop-

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* Accepted 15 July 2014.

ment. Four of the nine ASCE BOK professional outcomes are consistent with student outcomes for all engineering degree programs per ABET General Criterion 3; these four common outcomes are communication, teamwork, lifelong learning and professional and ethical responsibility. The other five ASCE BOK professional outcomes are not duplicated as student outcomes per ABET, but there are significant similarities. For example, both organizations recognize outcomes that include global impacts on engineering. Furthermore, ABET Program Criterion 1 also requires that three of the other five ASCE BOK professional outcomes must be addressed in a civil engineering curriculum, wherein the "program must prepare graduates to . . . explain basic concepts in management, business, public policy, and leadership [1]."

With the adoption of new student outcomes in the ABET Engineering Criteria in 2001, there was much concern raised about the teaching, learning, and assessment of professional skills. In their comprehensive review paper, Shuman et al. [3] state that the ABET professional skills "can certainly be mastered as part of a modern engineering education format that utilizes active and cooperative learning, recognizes differences in learning styles, and is cognizant of teaching engineering in its appropriate context." Guidance on the integration and assessment of select professional outcomes, such as teamwork [4] and lifelong learning [5], has been published in the engineering education literature. Curriculum reform efforts, on the other hand, represent a more comprehensive approach to meeting the new ABET expectations for accreditation. For example, the undergraduate civil engineering program at the University of Vermont commenced a department-level reform to enhance the student understanding and practice of professional engineering responsibilities through a systems approach complemented with service learning [6, 7]. Even new degree programs have been proposed to emphasize professional attributes, like Leadership Engineering at the University of Texas at El Paso [8]. This paper presents the professional impacts of an instructional approach called Environments for Fostering Effective Critical Thinking, or EFFECTs, which was developed and implemented in the Department of Civil & Environmental Engineering at the University of South Carolina.

2. Teaching-learning methodology

2.1 Environments for fostering effective critical thinking (EFFECTs)

EFFECTs are constructed with modular, inquiry based tools created to develop critical thinking skills, engineering judgment, and collaborative teamwork skills while improving the transfer of content knowledge. EFFECTs use problem-based learning techniques to create an environment for student-centered learning (SCL), which is a well-established model for higher education [9, 10] that has proven to be effective in engineering education [11]. In SCL environments the teacher serves as a facilitator of learning rather than a direct instructor of content, which promotes critical thinking and deep learning. In the EFFECTs framework, deep learning is supported with written communication products that focus students on improving their abilities for assimilation, interpretation and reflection. Ellis [12] characterizes deep learning as "preparation for future learning," which can be considered as a foundation for lifelong learning.

The framework and its sequencing of elements are represented in Fig. 1. The crux of each EFFECT is the formulation of a driving question in the context of a real engineering problem. The driving question serves as the background for students during their progression through the learning sequence. The sequence begins with a pre-decision worksheet, proceeds with *n* active learning modules, and concludes with a final product such as a design report or a post-decision worksheet. The driving question is designed to elicit student interest in the problem, and the decision worksheet requires students to prioritize the factors that affect the solution and make decisions about what information is needed to answer the driving question. In the first class period of an EFFECT, individuals complete a pre-decision worksheet and then collaborate in assigned teams to formulate a consensus response to the worksheet. This is followed with a designated

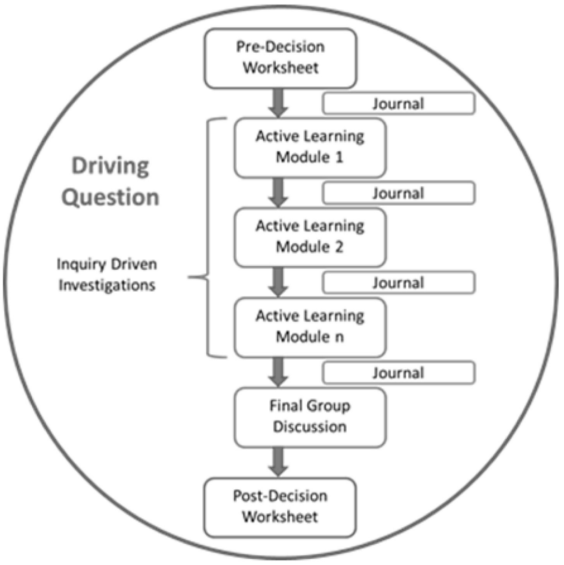

Fig. 1. EFFECT Instructional Framework.

number of consecutive classes containing active learning modules, which are completed in teams. Most EFFECTs utilize two to four class periods for active learning, such that each EFFECT spans two to three weeks of class instruction. After each module, students independently reflect on their activities and outcomes via online journal entries. Effective writing prompts for journal entries are open-ended and mechanistic. Journal prompts 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. At the end of the EFFECT sequence, students document their final answer to the driving question in written form, such as a final report or a post-decision worksheet. A more detailed discussion of the EFFECTs framework and its pedagogical components can be found in [13, 14].

Table 1. EFFECTs in Civil & Environmental Engineering Undergraduate Program

EFFECT Title[1]	**Driving Question**	**Course Title**	**Curriculum Component**	**Instructional Frequency**[2]
CM1: Model Selection	*What is the best model to describe the change in BOD concentration with time?*	ECIV 201: Computational Methods in Civil Engineering	lower division requirement	2012f
EN1: Water Filtration	*What are the dimensions of the activated carbon filter needed in the water filtration system for a small community?*	ECIV 101: Introduction to Civil Engineering	freshmen elective	2009f, 2007f
EN2: Oil Spill	*How much surfactant should be added to remediate an oil spill?*	ECIV 350L: Introduction to Environmental Engineering Laboratory	upper division elective	2011f
EN3: Trash to Energy	*How many homes can be powered by incinerating municipal solid waste?*	ECIV 350L: Introduction to Environmental Engineering Laboratory	upper division elective	2011f
EN4: Nanotechnology	*How many nano-sized iron particles are needed to remediate 15 trillion gallons of groundwater contaminated with trichloroethylene (TCE)?*	ENCP 490: Nanotechnology in Global Context	upper division elective	2012s, 2013s
GE1: Levee Reconstruction	*What weight of soil is needed to construct a 100-ft long section of earthen levee?*	ECIV 101: Introduction to Civil Engineering	freshmen elective	2007f-2011f
GE2: Tower Settlement	*How much ground surface settlement will occur in 20 years after construction of this tower?*	ECIV 330: Introduction to Geotechnical Engineering	upper division requirement	2012s
ST1: Earthquake Response	*What shape of the water tower support structure is needed to avoid its collapse during an earthquake?*	ECIV 101: Introduction to Civil Engineering	freshmen elective	2007f-2010f, 2012f
ST2: Bridge Deflection	*For a simply supported beam, what cross-sectional shapes will have the most and least deflection (assuming that the cross-section has an area of 137* in^2*)?*	ECIV 200: Statics	lower division requirement	2012s, 2013s
SU1: Parking Lot	*What is the area of the parking lot that should be used to calculate the volume of concrete?*	ECIV 101: Introduction to Civil Engineering	freshmen elective	2007f-2012f
TR1: Hurricane Evacuation	*How much time is required for safe evacuation from an approaching hurricane?*	ECIV 101: Introduction to Civil Engineering	freshmen elective	2007f
WR1: Water Tower	*How tall should a new water tower be to serve a small community?*	ECIV 101: Introduction to Civil Engineering	freshmen elective	2007f-2008f, 2010f-2011f
WR2: Pipeline Design	*What diameter is needed for the 2-mile long gravity pipeline to provide adequate water supply to the coffee tree nursery?*	ECIV 360: Introduction to Fluid Mechanics	lower division requirement	2012f

[1] CM = computational methods; EN = environmental; GE = geotechnical; ST = structural; SU = surveying; TR = transportation; WR = water resources. [2] f = fall semester; s = spring semester.

2.2 *Integration in civil and environmental engineering curriculum*

Table 1 summarizes the EFFECTs that have been developed and implemented in the undergraduate civil and environmental engineering curriculum at the University of South Carolina. At its inception in 2007, the EFFECT approach was created for a new elective course on Introduction to Civil Engineering for incoming freshmen. Six EFFECTs were developed specifically for that course, and four of the six are rotated through the course each fall semester. One of the main course objectives was to expose students to the various disciplines within the civil and environmental engineering profession. To that end, EFFECTs were designed to represent professional practices within environmental, geotechnical, structural, transportation, and water resources engineering, as well as for surveying. The EFFECTs instructional approach was found to be successful for integrating core knowledge with critical thinking of engineering problems [14, 15].

Beginning in 2011, the EFFECT approach was adopted for expansion into other departmental courses at the lower (freshman-sophomore) and upper (junior-senior) divisions. Seven new EFFECTs have been created and implemented in six courses over the past two years, as shown in Table 1. More detailed descriptions of specific EFFECTs have been published for Levee Reconstruction and Tower Settlement [13], Water Filtration [16], and Nanotechnology [17].

Not all of our current students have experienced EFFECTs at an equal exposure rate, however, because half of the impacted courses are electives and their implementation has been phased in over time. This unbalanced exposure should be mitigated as our expansion plans progress towards a more fully integrated curriculum. Five additional EFFECTs are in the developmental stages, and their implementation is anticipated during the next two years in five courses: ECIV 200—Statics; ECIV 210—Dynamics (lower division requirement); ECIV 303—Civil Engineering Materials (upper division requirement); ECIV 524—Structural Dynamics (upper division elective); and ECIV 530—Foundation Analysis and Design (upper division elective).

To gain a better understanding of how EFFECTs are impacting our curriculum, the ABET Criterion 3a-k outcomes and the ASCE BOK professional outcomes were rated for each one of the 13 EFFECTs identified in Table 1. The EFFECTs instructors rated each outcome using a three-point scale: 0, for not an outcome; 1, for a minor outcome; and 2, for a major outcome. The mean ratings for each ABET criterion are shown in Fig. 2. All but three of the criteria have mean ratings above 1, which suggests that most of the criteria can be considered to be programmatic outcomes of integrated EFFECTs. The three highest rated criteria are associated with technical skills; these skills are core elements of the EFFECT instructional approach, as described in the previous section. The next three highest rated skills are associated with professional attributes for effective communication, teamwork, and knowledge of contemporary issues. These are considered to be the core professional outcomes of integrating EFFECTs throughout the curriculum.

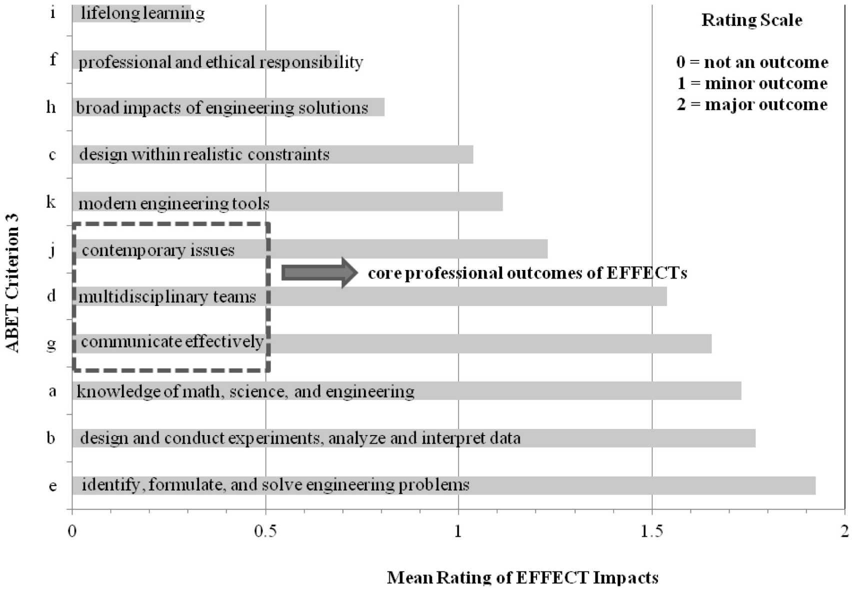

Fig. 2. Ratings of ABET Criterion 3a–k Outcomes in EFFECTs.

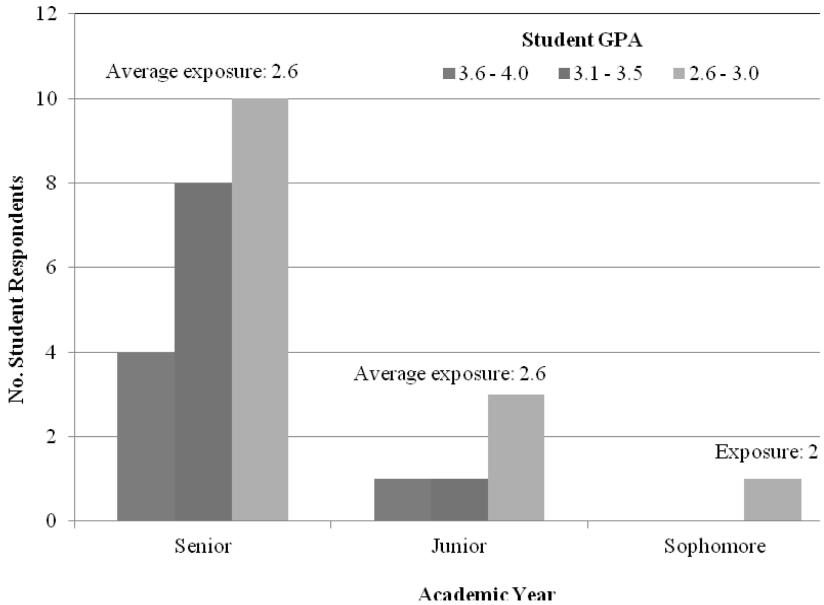

Fig. 3. Demographics of Student Respondents to Professional Skills Survey.

First, student learning of contemporary issues is linked to the driving question and decision worksheet. The EFFECTs instructional approach is centered in problem-based learning, and each engineering problem is posed to students in an appropriate and meaningful context. That context can be local, national, or global, and it is often set around a current event or issue. For example, the setting for Levee Reconstruction is in New Orleans, Louisiana, where students are tasked with rebuilding the earthen levee system after sections failed when Hurricane Katrina struck the region in 2005. Similarly, the Oil Spill is set in the same region of the southeastern U.S., where students are tasked with cleaning up the oil spill from the Deepwater Horizon disaster in the Gulf of Mexico in 2010. Nanotechnology, on the other hand, creates a setting that couples two important and contemporaneous issues: (1) understanding the new field of nanotechnology in an engineering context, and (2) how it can be applied to remediate contaminated groundwater supplies in third world countries, such as Bangladesh.

Second, the impacts of EFFECTs on teamwork are multifaceted. To understand these impacts, the approach to multidisciplinary teaming must be defined. ABET Criterion 3 identifies this student outcome as “an ability to function on multidisciplinary teams.” ASCE BOK, on the other hand, simply refers to teamwork. The interpretation of this outcome, and thus the corresponding instructional methods and assessments, are all at the discretion of the program; specific examples can be found in [18, 19]. In our case, a multidisciplinary team can be defined as a group of individuals, with different experiences and skills that complement each other, working together to achieve a common goal. Students are expected to understand team roles; fulfill his/her role; provide input; and listen to team members. Most importantly, the EFFECTs are designed to emphasize student experiences with the functional aspects of teams, including team management, communication, idea sharing, conflict resolution, and decision making.

The active learning strategies incorporated within the EFFECTs framework utilize team-based assignments, experiments, and tasks. Teams must work together to achieve a consensus as part of their in-class activities. For example, each EFFECT requires the completion of a group decision worksheet, which must be based on input and discussion of the individual decision worksheets completed by each team member. Hands-on exercises are also team-based, which includes the open-ended design of lab experiments (e.g., Oil Spill and Trash to Energy) and the design, construction, and testing of bench-scale physical models (e.g., Levee Reconstruction and Earthquake Response), for examples.

Third, oral and written communication skills are integrated throughout each EFFECT. Oral communication is embedded in the active learning modules in various forms that include interactive lecturing, think-pair-share exercises, team discussions, and team-based presentations of experimental designs, models, and proposed solutions. Individual students must also prepare various written products, such as the decision worksheet (via hand written responses), journal entries (via online tools), and a formal design or experimental report (via word processing software).

The five unique ASCE BOK professional outcomes rated much lower than the ABET outcomes. (Recall that four of the ASCE BOK professional outcomes are duplicated in ABET Criterion 3.) Mean ratings for public policy, business and public administration, globalization, leadership, and professional attitudes were less than 0.35. With mean ratings much less than 1, none of these outcomes are currently met, at a significant level, through the integration of EFFECTs across the curriculum. Individual EFFECTs, however, can make meaningful contributions to one or more of these professional outcomes. For example, globalization is considered to be a major outcome from Trash to Energy and a minor outcome from Nanotechnology.

3. Main results and actual benefits of the approach for promoting professional skills

3.1 Student survey of professional skills acquired through EFFECTs

In the spring 2013, an optional online survey was distributed to civil and environmental engineering students enrolled in senior level courses. A total of 28 students submitted a complete survey, which represents a return rate of approximately 40%. In terms of demographics, students were asked to indicate (1) academic class status; (2) grade point average (GPA) on a 4.0 scale; and (3) the total number of courses (current and completed) with an EFFECT. Fig. 3 summarizes the distribution of student respondent demographics. Most respondents (78%) were senior students in either their final semester or penultimate semester. However, the average exposure to EFFECTs is about the same regardless of academic class. There is also an equal distribution of student respondents with a GPA $>$ 3.0 and a GPA $\leq$ 3.0. It should be noted that no respondents indicated a GPA $<$ 2.6.

The survey instrument was comprised of 26 questions constructed from the ABET Criterion 3a-k outcomes and the ASCE BOK professional outcomes. Response options for all questions were based on a Likert scale ranging from Strongly Agree (numerical rating of 1) to Strongly Disagree (numerical rating of 5). The response distributions are provided in Tables 2 through 5.

Survey results indicate that EFFECTs have a positive impact on both technical and professional skills. Tables 2 and 3 summarize student responses to the practice of ABET technical and professional skills, respectively. Responses in Table 2 are given for five questions on the technical outcomes identified in Criterion 3a (*an ability to apply knowledge of mathematics, science, and engineering*); 3b (*an ability to design and conduct experiments, as well as to analyze and interpret data*), which was split into two questions; 3e (*an ability to identify, formulate, and solve engineering problems*); and 3k (*an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice*). The average rating for each one of the technical skills is less than 2.5 with at least a 50% sum of positive responses (strongly agree and agree). Not all EFFECTs incorporate structured experiments and therefore do not require use of lab or field equipment, which might contribute to the reduced number of positive responses on conducting experiments (Criterion 3e) and using modern tools (Criterion 3k).

Table 3 summarizes responses to six questions on professional outcomes identified in Criterion 3d (*an ability to function on multidisciplinary teams*); 3f (*an understanding of professional and ethical responsibility*), which was split into two questions; 3g (*an ability to communicate effectively*), which was divided into questions on oral and written communications skills; and 3j (*a knowledge of contemporary issues*). Like the technical outcomes, the average rating for each one of the professional outcomes is less than 2.5 with at least a 50% sum of positive responses (strongly agree and agree). The highest rated response (1.56 average rating) to all 11 questions in Tables 2 and 3 was for a professional outcome, working in teams (Criterion 3d), which received a 100% sum of positive responses.

Table 2. Likert Scale Distribution of Student Responses on Technical Skills

Q1. Overall, the EFFECT exercises created opportunities for me to ...

Rating	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Average Rating
Apply my knowledge of math, science, and engineering.	29.6% (8)	**55.6% (15)**	14.8% (4)	0.0% (0)	0.0% (0)	1.85
Identify and solve engineering problems.	29.6% (8)	**59.3% (16)**	11.1% (3)	0.0% (0)	0.0% (0)	1.81
Design and conduct experiments.	18.5% (5)	**37.0% (10)**	33.3% (9)	11.1% (3)	0.0% (0)	2.37
Analyze and interpret data.	22.2% (6)	**63.0% (17)**	11.1% (3)	3.7% (1)	0.0% (0)	1.96
Use modern engineering equipment, tools and techniques.	18.5% (5)	**37.0% (10)**	29.6% (8)	7.4% (2)	7.4% (2)	2.48

Table 3. Likert Scale Distribution of Student Responses on Professional Skills

Q2. Overall, the EFFECT exercises created opportunities for me to ...

Rating	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Average Rating
Work in teams.	44.4% (12)	**55.6% (15)**	0.0% (0)	0.0% (0)	0.0% (0)	1.56
Work on written communication skills.	25.9% (7)	**48.1% (13)**	14.8% (4)	7.4% (2)	3.7% (1)	2.15
Work on oral communication skills.	11.1% (3)	**63.0% (17)**	18.5% (5)	7.4% (2)	0.0% (0)	2.22
Learn about contemporary issues.	22.2% (6)	**40.7% (11)**	25.9% (7)	7.4% (2)	3.7% (1)	2.30
Understand professional responsibilities of engineers.	14.8% (4)	**44.4% (12)**	29.6% (8)	11.1% (3)	0.0% (0)	2.37
Understand ethical responsibilities of engineers.	22.2% (6)	**40.7% (11)**	25.9% (7)	11.1% (3)	0.0% (0)	2.26

Table 4. Likert Scale Distribution of Student Responses on Professional Considerations of Engineering Problems

Q3. Overall, the EFFECT exercises created opportunities for me to work on an engineering solution with consideration of ...

Rating	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Average Rating
Economic impacts.	22.2% (6)	**37.0% (10)**	29.6% (8)	11.1% (3)	0.0% (0)	2.30
Environmental impacts.	22.2% (6)	**59.3% (16)**	11.1% (3)	7.4% (2)	0.0% (0)	2.04
Social impacts.	18.5% (5)	**44.4% (12)**	25.9% (7)	11.1% (3)	0.0% (0)	2.30
Political impacts.	14.8% (4)	25.9% (7)	25.9% (7)	**33.3% (9)**	0.0% (0)	2.78
Ethical impacts.	19.2% (5)	**30.8% (8)**	23.1% (6)	23.1% (6)	3.8% (1)	2.62
Health and safety impacts.	18.5% (5)	**40.7% (11)**	18.5% (5)	18.5% (5)	3.7% (1)	2.48
Constructability.	22.2% (6)	**48.1% (13)**	11.1% (3)	14.8% (4)	3.7% (1)	2.30
Sustainability.	18.5% (5)	**40.7% (11)**	22.2% (6)	11.1% (3)	7.4% (2)	2.48

Table 5. Likert Scale Distribution of Student Responses on ASCE BOK Professional Skills

Q4. Overall, the EFFECT exercises created opportunities for me to learn about the importance of engineering and ...

Rating	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Average Rating
Public policy.	11.1% (3)	**37.0% (10)**	29.6% (8)	18.5% (5)	3.7% (1)	2.67
Business and public administration.	11.1% (3)	**29.6% (8)**	29.6% (8)	25.9% (7)	3.7% (1)	2.81
Globalization.	14.8% (4)	18.5% (5)	**40.7% (11)**	22.2% (6)	3.7% (1)	2.81
Leadership.	23.1% (6)	**34.6% (9)**	15.4% (4)	26.9% (7)	0.0% (0)	2.46
Teamwork.	37.0% (10)	**40.7% (11)**	18.5% (5)	3.7% (1)	0.0% (0)	1.89
Professional attitude.	22.2% (6)	**37.0% (10)**	22.2% (6)	14.8% (4)	3.7% (1)	2.41
Lifelong learning.	26.9% (7)	**30.8% (8)**	23.1% (6)	15.4% (4)	3.8% (1)	2.38

ABET Criterion 3c (*an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability*) and 3h (*the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context*) were evaluated as part of a separate set of questions, with the results shown in Table 4. The highest rated response (2.04 average rating) was for environmental impacts, which is hypothesized to be the result of the larger number of environmental EFFECT opportunities for students. Furthermore, most of the environmental EFFECTs focus on problems with significant impacts on the environment, such as the Nanotechnology, Oil Spill, and Trash to Energy EFFECTs (see Table 1). The lowest rated responses were for political impacts, ethical impacts, health and safety impacts, and sustainability, which all received 50% or less positive responses. There is at least one EFFECT in the curriculum that incorporates one or more of these professional components (e.g., political impacts are incorporated in Levee Reconstruction; sustainability is incorporated in Trash to Energy). However, the cumulative exposure is not as high as for environmental impacts.

Table 5 provides results of student responses to questions on the ASCE BOK professional skills. The first three outcomes for understanding the importance of public policy, business and public administration, and globalization received less than 50% positive responses. The remaining skills, except for teamwork, were slightly more favorable but still received less than 60% positive responses. The student perceptions of these professional outcomes are not unexpected, and are somewhat consistent with the instructor assessments that these are not designed to be meaningful outcomes of the current EFFECTs, as discussed in a prior section.

3.2 Impact of multiple EFFECTs on professional skills

Almost one-third of the student respondents had just one course with an EFFECT. The remaining two-thirds of student respondents had two or more courses with EFFECTs. There was a marked difference in the responses between these two groups of students, especially with respect to the ABET Criterion 3 professional skills, as shown in Fig. 4. When exposed to at least two courses with EFFECTs, the average rating for each professional skill is 2.0 or less, with at least a 74% sum of positive ratings (strongly agree and agree). In contrast, the average ratings for students with a single course experience are higher and closer to neutral on the Likert scale, with no more than a 50% sum of positive ratings. The lone exception is for working in teams, which received 100% positive ratings regardless of the number of course opportunities. The results suggest there is the potential for significant impact on the student development of professional skills when EFFECTs are integrated throughout the curriculum.

A one-way analysis of variance (ANOVA) was selected for a comparison of means to determine if there is statistical significance in the student responses. Responses were categorized into three groups based on EFFECT exposure in one course; two courses; and three or more courses. A p-value of 0.05 is selected as the level of significance (i.e., at least one of the means is different at a 95% confidence level if $p < 0.05$). Table 6 provides the results of the ANOVA test on the means of a select number of ABET technical and professional skills. As shown in Table 6, there is a statistical difference in the means of student ratings for four of the ABET professional skills: oral communication, contemporary issues, professional responsibilities, and ethical responsibilities. The p-value of 0.051 for a fifth professional skill, written communication, is at the limit for statistical significance. As expected, there was no significant difference observed for work in teams. Interestingly, there were also no significant differences observed for the technical skills. This contrast in findings implies that, for this limited sample set, repeated exposure of EFFECTs in multiple courses can contribute to a more meaningful impact on professional outcomes; however, it is not observed to be as critically important for technical outcomes.

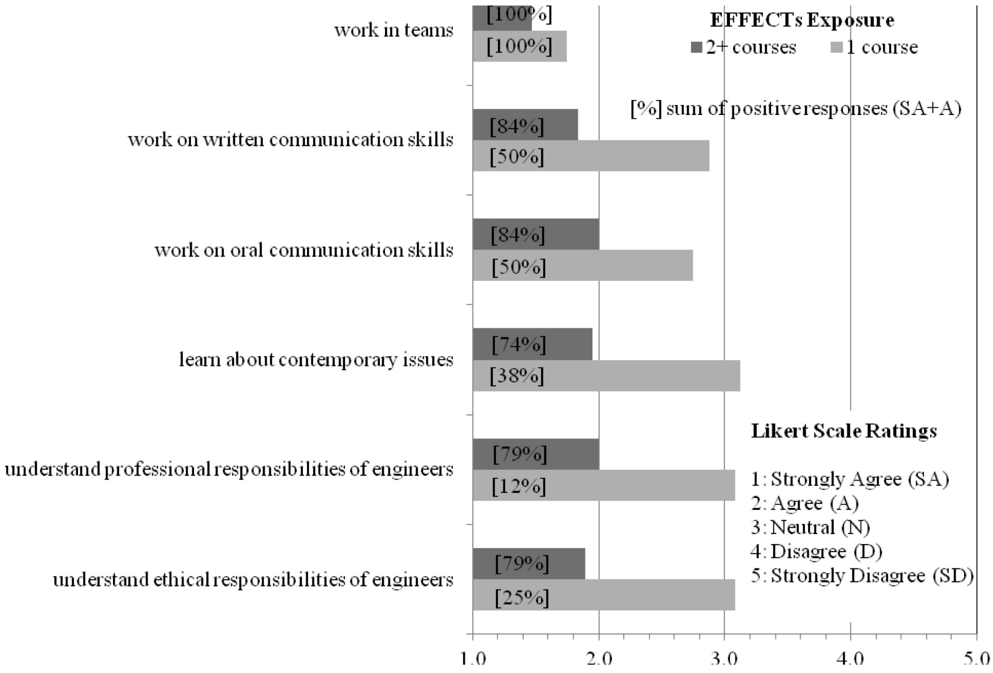

Fig. 4. Multiple EFFECT Exposures on ABET Professional Skill Ratings.

Table 6. ANOVA Test of EFFECT Exposure on ABET Technical and Professional Skills

ABET Criterion 3 Outcomes		**1 course** *n* **= 8**	**2 courses** *n* **= 7**	**3+ courses** *n* **= 12**	**p < 0.05?**
Technical skills	Apply knowledge of math, science, and engineering.	2.25	1.57	1.75	0.106
	Identify and solve engineering problems.	2.12	1.71	1.67	0.248
	Design and conduct experiments.	2.75	1.86	2.42	0.174
	Analyze and interpret data.	2.38	1.71	1.83	0.135
	Use modern engineering equipment, tools and techniques.	3.12	2.00	2.33	0.126
Professional skills	Work in teams.	1.75	1.43	1.50	0.430
	Work on written communication skills.	2.88	1.86	1.83	0.051
	Work on oral communication skills.	2.75	1.86	2.08	**0.043**
	Learn about contemporary issues.	3.12	1.86	2.00	**0.018**
	Understand professional responsibilities of engineers.	3.25	1.86	2.08	**0.001**
	Understand ethical responsibilities of engineers.	3.12	1.71	2.00	**0.003**

4. Future issues

This paper provides a foundation for understanding the role of EFFECTs on student outcomes, both technical and professional, when integrated in the curriculum. It also raises a number of future issues that can and should be addressed based upon the findings in this initial investigation. Three issues are described herein.

(1) Assessment of professional student outcomes associated with EFFECTs should be conducted on an annual basis as EFFECTs are expanded through the civil and environmental engineering curriculum. The current investigation provided a unique opportunity to evaluate the impacts of single and multiple courses with EFFECTs on the student development of professional skills of upper division students (seniors, primarily). As expansion continues, the student exposure will gradually become more aligned with academic status. This means that lower division students (freshmen-sophomores) will have fewer courses with EFFECTs than upper division students (juniors-seniors), and the average number of courses that seniors will have completed with EFFECTs should be higher than the current average of 2.6. Thus, future survey instruments should be distributed to all undergraduate students in the program, which will facilitate longitudinal assessment of professional skills as students progress through our curriculum. Future surveys should also be designed to identify the actual courses with EFFECTs for each respondent, rather than just the number of courses. With this information, student responses can be evaluated based on a direct comparison to the expected outcomes for each subset of EFFECTs.

(2) There are opportunities to improve the professional impacts of EFFECTs, in particular with respect to the ASCE BOK professional outcomes. This can be accomplished by enhancing active learning modules in existing EFFECTs, and/or through deliberate inclusion of one or more of these outcomes in the developmental stages of new EFFECTs. This process can be aligned with our current departmental initiative to create two curriculum maps, one for content and one for skills.

(3) Ultimately, the critical research question should focus on the translation of these academic experiences to professional practice. In other words, how do students transfer what was learned from the EFFECT instructional approach to the engineering workplace? This research question can be evaluated within two independent groups. The first approach is to evaluate current students with engineering work experience, either through part-time employment during the academic year (in which a number of our students participate), full-time summer employment or internships, or cooperative education programs. The second approach is to evaluate post-graduates with full-time engineering positions, preferably within their first 12 to 18 months of graduation to facilitate free recall of their EFFECTs experiences.

5. Conclusions

The Environments for Fostering Effective Critical Thinking, or EFFECTs, is an instructional approach that has been embedded in the civil and environmental engineering undergraduate program at the University of South Carolina. To date, thirteen unique EFFECTs have been developed and implemented in seven different courses, ranging from freshman to senior level classes. This paper presents an overview of the EFFECTs and their impacts on student outcomes, both technical and professional, per ABET and ASCE guidelines. The following conclusions are made based on the findings presented in this paper.

(1) There are three core professional student outcomes from EFFECTs:
   - an ability to function on multidisciplinary teams, ABET Criterion 3d (and consistent with ASCE BOK Outcome 21, teamwork);
   - an ability to communicate effectively, ABET Criterion 3g (and consistent with ASCE BOK Outcome 16, communication); and
   - a knowledge of contemporary issues, ABET Criterion 3j.

(2) Effective communication and teamwork were the two highest instructor-rated professional skills associated with the current set of EFFECTs. The mean instructor ratings were above 1.5, indicating that these two skills are major (rating of 2) or minor (rating of 1) outcomes in all EFFECTs.

(3) Teamwork was the highest student-rated outcome, technical or professional, from EFFECTs. It was the only outcome to receive a 100% positive response from the student survey group, meaning that all respondents selected Strongly Agree or Agree to the statement on opportunities to engage in teamwork.

(4) Students who engaged in EFFECTs in multiple courses rated the impacts on professional skills much higher than students who engaged in a single course with EFFECTs. The difference in means was statistically significant for oral communication skills; contemporary issues; professional responsibilities of engineers; and ethical responsibilities of engineers.

Acknowledgements—This material is based upon work supported by the National Science Foundation under Grant Nos. DUE 0633635 and DUE 1022971.

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