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Environmental Engineering Capstone Design Course Learning Outcomes Performance Perceived Through Multiple Lenses: Students, Faculty and Professional Engineers

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Abstract

Integration of a competition prompt into a capstone design course challenged students to apply the skills and content knowledge gained throughout their studies to address a complex problem. Texas Tech University (TTU) uses a prompt from the Water Environment Association of Texas (WEAT) student design competition to address the ABET specified program and student outcomes while also providing a real world design challenge for the students to provide treatment upgrades to a municipal wastewater treatment plant. TTU's course solicited advisement from two consulting professional environmental engineers, in addition to faculty guidance. Incorporating these professional engineers into the class helped to bridge the gap between academics and practical applications as the engineers provided feedback to student teams throughout the design process. The two semester course promotes problem-based learning and allows students to enhance their professional and communication skills such as group collaboration, problem solving and presentation of technical designs. Self-evaluation by students in addition to professional engineers and faculty evaluations throughout the course provide similar and contrasting perceptions of how learning outcomes were met. Learning outcomes were used to evaluate student work during the design course and responses from various views allowed for assessment of student preparedness following completion of the course. Learning outcomes were presented to students, professional engineers and faculty for evaluation using a Likert scale. The responses provided data of how the three groups perceived the relevance of the course outcomes addressed to the students' future careers. Responses to pre and post course questionnaires assessed the three evaluators' perceptions of student areas for improvement and strengths as related to the learning outcomes. This study allowed for similarities and differences to be identified between the three groups of stakeholders: students, faculty, and professionals. This paper addresses the performance of an environmental engineering capstone design course following the integration of the WEAT design prompt and highlights components of the course weaknesses. Additionally, longitudinal data showcases students performing well following the implementation of the WEAT design prompt.

Introduction

Capstone design courses vary between engineering programs and can be structured to include industry partners, service-learning projects for communities or competition design projects[1]. Utilization of a competition prompt as the capstone design project provides many benefits for student education[2]. For instance, students may receive a real-world problem submitted by a regional municipal utility tasking them with the job of treatment upgrades to improve plant performance. Unlike the use of hypothetical academic prompts, additional opportunities are given to the students when they engage with a competition prompt, such as the ability to tour the project facility, receive detailed data from the plant and interact with utility personal and practicing engineers who work daily at the treatment plant[3-5].

The Water Environment Association of Texas (WEAT) student design prompt can aid faculty in development of the course providing a realistic problem for students to work on during the capstone design course. Additional advisement from practicing engineers can provide additional resources and feedback for students. Practicing engineers provide students with guidance on how industry works and can bring light to elements such as project management, economic, social, political and ethical considerations that are not discussed extensively during undergraduate coursework. Practicing engineers work with manufactures and municipalities daily; therefore, have greater exposure to current practices and can help strengthen faculty instruction or fill in the gaps of knowledge instructors are not able to fill for the student's education[6].

Adaptation of the WEAT student design prompt allows students the opportunity to learn the iterative aspect of design and the importance of redesign skills during a capstone design course utilizing a real-world problem of providing design upgrades for a municipalities wastewater treatment plant (WWTP). Development and reasoning of initial design is tested once students are asked to provide specifications for proposed upgrades. Teams learn the importance of problem-solving skills and the ability to redesign after performance evaluations[7].

Contribution of course to professional component of an environmental engineering curriculum can be satisfied through oral and written presentations required with regional or national competitions. Students are given the opportunity to present before a panel of judges expanding their professional network by the opportunity of attending and competing at the WEAT conference. Additionally, a competition prompt provides structure for the students and allows them to develop oral and written presentations for a client (municipality); therefore, providing students with real-world application of engineering solutions[2, 8].

ABET accreditation provides assurance that a university program meets the quality standards established by the profession for which the program prepares it students. In order for an environmental engineering degree program to comply with ABET requirements, students are tasked with a capstone design course applying learning outcomes designed to address components of the profession students should be exposed to upon graduation. ABET encourages life-long education and for students to develop skills needed to perform tasks during their professional career[8]. Evaluation of learning outcomes from multiple perceptions allows course strengths and areas for improvement to be highlighted.

This paper will discuss a case study of how students perform within a capstone design course utilizing a design-competition problem statement and advisement of practicing engineers. Student performance of ABET learning outcomes was evaluated as perceived by students, faculty and practicing engineers. Study objectives include: (1) assessment of how the three evaluators perceived students understanding of course material and accomplishment of ABET course and program outcomes, (2) student self-evaluation of strengths and areas for improvement developed during the capstone design course, and (3) longitudinal study of how students performed once integration of the WEAT prompt with environmental engineering capstone course occurred.

Capstone Design Course Structure and Project Statement

Texas Tech University's (TTU) Master of Environmental Engineering (MEnvE) is a 5-year program awarding students Bachelors of Science and Masters of Engineering concurrently, upon graduation. Students are enrolled in graduate level courses the final year of the program, including a year-long capstone design course serving as students' thesis research. The environmental engineering capstone design course is structured between sequential semesters (EnvE 5305/5306) adapting the WEAT student design competition prompt. Integration of the WEAT design prompt in TTU's capstone design course started during the 2011-2012 academic year. Amendments to the WEAT project statement were made to address student ABET learning outcomes outlined in subsequent sections. Students were not required, but highly encouraged, to participate in the actual design competition and participation did not impact final student grades of the capstone design course.

During the first semester, EnvE 5305, students were provided a real-world problem of providing upgrades for the municipal WWTP adapted from the WEAT student design prompt. The students were required to address enhanced nutrient removal to meet future stringent regulations, enhanced solids treatment for production of biosolids A versus biosolids B and provide 1 million gallon per day (MGD) type 1 reclaimed water. Students were tasked with performing a capacity analysis, performance evaluation, develop a design process selection criterion for selection of process upgrades, perform a plant solids balance, perform preliminary unit operation and process upgrade design and provide an upgrade cost analysis.

The second semester, EnvE 5306, is a continuation of work performed during EnvE 5305 concerning proposed upgrades for the WWTP rehabilitation. Students were tasked in the second semester to develop an upgraded plant layout, describe overall liquid and solid process design upgrades, provide a hydraulic profile and submit a thorough cost analysis of upgrades proposed to meet prompt objectives.

Two faculty members instructed students during the sequential courses, providing guidance and resources for each group. Additionally, two practicing engineers volunteered their time to act as advisors for students, providing feedback and examples of how consulting engineers perform tasks similar to those required during the course. Practicing engineers were present for the first class meeting when the design prompt was introduced to students. During the initial class meeting, practicing engineers introduced their educational and professional background in addition to general duties of consulting engineers. During the remainder of the course the practicing engineers interacted with the students remotely by providing comments on bimonthly report draft submittals through email. Bimonthly conference calls were held, allowing students the opportunity to provide oral updates and receive feedback from practicing engineers on design progress. Practicing engineers reviewed final written reports submitted electronically and then were present for final oral presentations, providing feedback to individual teams.

Capstone Design Course Components

Students received a syllabus at the beginning of each semester detailing the requirements and key deadlines they must meet during the courses. For the rest of the paper only the first capstone design course (EnvE 5305) will be discussed. Course components allowed students to gain experience in time management, project management, group collaboration, technical, and communication skills.

For the 2014-2015 academic year, 15 students, 6 women and 9 men, were enrolled in the sequential capstone design courses and divided into 5 teams of 3 by the faculty instructors. Determination of the groups was achieved based on the responses students provided from a pre-questionnaire administered the first class meeting. The questionnaire students took will be discussed further in subsequent sections of this paper.

Students were evaluated and assessed by faculty based on the following components making up an individual's course grade: timesheets, project schedule, team evaluation, project updates, final written report and oral presentations. Weekly timesheets helped the two faculty members leading the course evaluate how the work load was divided amongst group members. Project schedules were developed for the semester providing students with deadlines allowing for development of student project and time management skills. Peer and self evaluations were due at the end of the semester providing students with the opportunity to assess how they perceived each group member performed throughout the course. Group evaluations focused on teamwork and group communication during the semester.

Project updates were given by student teams bimonthly, totaling six updates, throughout the semester allowing students the opportunity to develop their oral skills. Project updates were five minute presentations covering the team's progress and the next tasks the teams would address regarding the proposed upgrades to the WWTP. Project updates were given to faculty members in a conference room setting with practicing engineers calling in to provide students with feedback and additional resources. As per the project schedules, written report updates were submitted bimonthly to both faculty instructors and practicing engineers electronically for comments and feedback on team progress. The final product for the EnvE 5305 course was a written report outlining proposed upgrades for the municipal WWTP. The final component of students' course grade included a 20 minute oral presentation given by each team detailing their proposed plant upgrades followed by a 10 minute question and answer session. Faculty, practicing engineers and students were present for oral presentations. Table 1 describes how the course components were weighted for student's final course grades.

Table 1: EnvE 5305 course components

Course Component	Percentage
A) Timesheets	5%
B) Project Schedule	10%
C) Team Evaluation	10%
D) Project Updates	10%
E) Final Product: Written report outlining proposed treatment upgrades	45%
F) Oral Presentation	20%

ABET learning outcomes were presented to students in the syllabus outlining expectations of the capstone design course. Outcomes were to be addressed through tasked course components presented in Table 1. Table 2 summarizes ABET student outcomes and program specific outcomes (PSO) the environmental engineering capstone design course addressed during the first semester course (EnvE 5305). The course was not built to address all outcomes equally, but to satisfy ABET requirements of providing students with the exposure to diverse topics and develop their skill set through completion of the design course preparing them for a professional career in the environmental engineering field.

Table 2: ABET student outcomes and program specific program outcomes addressed during capstone design course

Student Outcomes
1) an ability to apply knowledge of mathematics, science, and engineering
2) an ability to design a system, component, or process to meet desired needs within realistic constraints
3) an ability to identify, formulate, and solve engineering problems
4) an understanding of professional ethical responsibility
5) an ability to communicate effectively
6) the broad education necessary to understand the impact of engineering solutions in a global and societal context
7) a recognition of the need for, and an ability to engage in life-long learning
8) a knowledge of contemporary issues
9) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
Program Specific Outcomes
1) The curriculum has prepared graduates to apply knowledge of mathematics through differential equations, probability and statistics, calculus-based physics, chemistry (including stoichiometry, equilibrium, and kinetics)
2) The curriculum has prepared graduates to apply knowledge of earth science, a biological science, fluid mechanics
3) The curriculum must prepare graduates to formulate material and energy balances, and analyze the fate and transport of substances in and between air, water and soil phases
4) Design environmental engineering systems that include considerations of risk, uncertainty, sustainability, life-cycle principles, and environmental impacts; and apply advanced principles and practice relevant to the program objectives
5) The curriculum must prepare graduates to understand concepts of professional practices, project management, and the roles and responsibilities of public institutions and private organizations pertaining to environmental policy and regulations

For the capstone design course to address program specific outcomes, additional tasks were added to the supplied WEAT design prompt. To satisfy Program Specific Outcome 3, odor pollution control needed to be considered throughout the treatment process by the students. The design prompt already addresses both liquid and solid phases but the prompt was adjusted to address the air phase; therefore, satisfying Program Specific Outcome 3. Additionally, students were tasked with including life-cycle principles to their design even though the original WEAT design prompt did not require such consideration; therefore, Program Specific Outcome 4 was addressed.

Course Assessment/Evaluation Instruments

This paper will focus on how students, faculty members and practicing engineers perceived ABET student and program specific outcome achievement through completion of the capstone design course outlined above. Student performance of learning outcomes and PSOs during the design course was evaluated through multiple instruments, summarized in Table 3 below. Evaluation instruments included a survey implementing a Likert scale to all three evaluating parties (Table 5 and 6), course grading rubric for faculty (Table 4), an open-ended pre-questionnaire for students (Figure 1), post-questionnaire for students (Figure 2) and post-questionnaire for practicing engineers (Figure 3).

Table 3: Assessment instruments administered

Assessment Instrument	**Assessment Type**	**Administered To**	**Administered By**	
EnvE 5305 Pre-questionnaire	Questionnaire	Students	Faculty	Figure 1
EnvE 5305 Post-questionnaire	Questionnaire	Students	Faculty	Figure 2
EnvE 5305 Post-questionnaire	Questionnaire	Practicing Engineers	Teaching Assistant	Figure 3
Course Evaluation of Student Performance	Rubric	Students	Faculty	Table 4
Ranking Student Performance of Student Learning Outcomes	Likert Survey	Students, Faculty and Practicing Engineers	Teaching Assistant	Table 5
Ranking Student Performance of Program Specific Outcomes	Likert Survey	Students, Faculty and Practicing Engineers	Teaching Assistant	Table 6

Evaluation of the MEnvE capstone design course included open-ended questionnaires provided to the two parties; students and practicing engineers. Students were given a pre-questionnaire the first class providing the instructors better understanding of how students perceived their performance thus far in their degree program. Figure 1 outlines the questions asked of the students. In addition to asking students what they perceived their strengths and areas for improvement, students were asked to provide information of how they performed in pre-requisite courses to the capstone design course. Responses from the questionnaire provided the faculty instructors with information to determine how teams were formed for the project. Once teams were assigned they were to work together for both design courses, EnvE 5305/5306.

ENVE 5305 Questionnaire

Please answer the following:

1) Name:
2) Provide your undergraduate and graduate GPA:
3) Provide your grades in the following classes:
   a. ENVE 4385/CHEM 4363 *(Microbiology Applications in Environmental Engineering)*
   b. ENVE 4307 *(Physical and Chemical Municipal Wastewater Treatment)*
   c. ENVE 4399 *(Biological Municipal Wastewater Treatment)*
   d. CE 4353/CE 5360 *(Design of Hydraulic Systems)*
4) Based on class experience or practical experience:
   a. Please describe your strengths in areas related to your discipline (i.e. water, wastewater, etc.)
   b. Please describe your areas for improvement related to your discipline.
5) Please indicate 1 person you cannot work with in this course. DO NOT provide the reason.
6) Please indicate your top learning objective (what you want to learn about most) in this course.
7) Please indicate if you are interested in participating in the WEAT Project. Yes No

Figure 1: EnvE 5305 pre-questionnaire for students

Students, faculty and practicing engineers were provided a survey at the end of the course EnvE 5305 and asked to provide a rating of how they perceived each outcome was addressed using the Likert scale from 5 to 1; where 5 the evaluator strongly agrees the student met the outcomes and 1 indicates the evaluator strongly disagrees outcomes were met at completion of the capstone design course, EnvE 5305. The survey provided a ranking for each ABET student and program specific outcome for the MEnvE program as perceived by the three parties. Table 5 and 6, in assessment results and discussion section below, provides the assessment tools implemented to survey how students performed during the course and program and how well each evaluating party perceived students met ABET student and program specific outcomes.

In a post-questionnaire (Figure 2) completed at the same time as the ABET Likert scale survey, students were asked what they perceived as their individual strengths and areas for improvement after completion of the course. In the post questionnaire, students were asked to provide feedback of how the design course prepared them for a career in industry and how the course could be improved to help better prepare students for their careers.

Please answer the following questions:

1) Please comment on how the capstone design course has prepared students for a career in industry.

2) Provide suggestions for the course to better prepare students for their career.

3) Based on **class experience** or practical experience:
   a. Please describe your strengths in areas related to your discipline (i.e. water, wastewater, etc.)
   b. Please describe your areas of weakness and ways of improvement related to your discipline.

Figure 2: EnvE 5305 post-questionnaire for students

Practicing engineers were provided a questionnaire (Figure 3) at the end of the course soliciting feedback of student performance throughout the capstone design course. Practicing engineers were asked their motivation and perceived benefits of serving as an advisor/mentor for students enrolled in EnvE 5305. Practicing engineers were also asked to comment on how they perceived the capstone design course prepared students for a career in industry and provide suggestions for EnvE 5305 course improvements to better prepare students for their careers.

Please answer the following questions regarding the capstone design course:

What was the motivation and benefits of serving as an advisor/mentor for environmental team design at the [University]?

Please comment on how the capstone design course has prepared students for a career in industry.

Provide suggestions for the course to better prepare students for their career.

Figure 3: EnvE 5305 post-questionnaire for practicing engineers

A grading rubric (Table 4) was utilized by the faculty for evaluation of each team's performance based on the final product submitted. The rubric evaluated the team's written report and oral presentation. Table 4 outlines the instrument used for assessment of students final product submitted. Each factor was ranked 1 to 5 where 5 indicates a letter grade A, 4 letter grade B, 3 letter grade C, 2 letter grade D and 1 is a failing grade. The written report was evaluated based on overall format and content for a total of 140/200 points for the final product. Within the report the students were asked to address certain tasks pertaining to the rehabilitation and upgrades of the assigned municipal WWTP. The required tasks were evaluated individually within the report based on content such as organization, grammar, logic and completeness. Final oral presentations accounted for 35/200 points of the final product submittal. The oral presentations were evaluated based off of elements found in Table 4. The final 25/200 points were earned from group project management throughout the capstone design course.

Table 4: Faculty evaluation instrument of student performance based on final product submitted

Factor	Student Rank (1-5)	Factor	Student Rank (1-5)
Report Format		Cost	
Format		Cost data inclusion	
Layout		Grammar	
Front material		Appendixes	
Back material		Organization	
Figures		Uniformity	
Tables		Completeness of calculations	
References		Accuracy of calculations	
Overall uniformity		TOTAL REPORT (140 pts)	
Report Content		Presentation	
Evaluation		Time	
Organization		Use of time	
Logic and completeness		Slide appearance and content	
Alternative Selection		Organization of speech	
Organization of sections		Usage of slides	
Logic of presentation		Content of Speeches (1/2)	
Completeness of discussion		Poise and delivery (1/2)	
Grammar		Question and Answer Period	
Solids Balance		TOTAL PRESENTATION (35 pts)	
Organization		Project Management	
Logic and completeness		Team Time Management	
Grammar		Performance as rated by peer	
Design		Ability to accept guidance	
Flow Diagram (3 or 4)		Utilization of all resources	
Organization of sections		Ranking of deliverables with ideal	
Logic of presentation		TOTAL PM (25 pts)	
Completeness of discussion		Final Project Total out of 200 pts	

Course Assessment/Evaluation Results and Discussion

This paper includes assessment of student performance following completion of the first semester, EnvE 5305, of the MEnvE capstone design courses. Table 5 and 6 show the rankings of how the three parties perceived student performance addressed ABET Student and Program Specific Outcomes. The capstone design course is part of TTU's MEnvE curriculum and serves as a master thesis research, allowing students the opportunity to identify resources required and interpret data to provide a design solving a real-world problem.

Table 5: Students, faculty and practicing engineers ranking of Student Outcomes performance after completion of EnvE 5305

	Students	**Faculty**	**PE**
Student Outcomes	**Average± Std. Dev.**	**Average± Std. Dev.**	**Average± Std. Dev.**
1) An ability to apply knowledge of mathematics, science, and engineering	4.53±0.52	4.00±0.00	5.00±0.00
2) An ability to design a system, component, or process to meet desired needs within realistic constraints such as:			
2a) Economic	3.60±0.91	4.00±1.00	2.00±0.00
2b) Environmental	4.07±0.80	5.00±0.00	5.00±0.00
2c) Social, Political, and Ethical	3.13±0.92	3.50±0.50	2.00±0.00
2d) Health and Safety	3.73±0.96	4.00±0.00	5.00±0.00
2e) Manufacturability	3.07±0.88	2.00±1.00	3.00±0.00
2f) Sustainability	3.40±0.99	4.00±1.00	3.00±0.00
3) An ability to identify, formulate, and solve engineering problems	4.47±0.74	4.50±0.50	5.00±0.00
4) An understanding of professional and ethical responsibility	4.07±0.80	4.00±1.00	3.00±0.00
5) An ability to communicate effectively	4.21±0.89	4.00±1.00	4.00±0.00
6) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	4.33±0.82	4.00±0.00	5.00±0.00
7) A recognition of the need for, and an ability to engage in life-long learning	4.33±0.98	3.50±0.50	4.00±0.00
8) A knowledge of contemporary issues	3.93±0.80	4.50±0.50	5.00±0.00
9) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	4.20±0.86	3.50±0.50	5.00±0.00

* Rank (5-Strongly Agree; 1-Strongly Disagree)

Table 6: Students, faculty and practicing engineers ranking of Program Specific Outcomes performance after completion of EnvE 5305

	Students	**Faculty**	**PE**
Program Specific Outcomes	**Average± Std. Dev.**	**Average± Std. Dev.**	**Average± Std. Dev.**
1) The curriculum has prepared graduates to apply knowledge of mathematics through differential equations, probability and statistics, calculus-based physics, chemistry (including stoichiometry, equilibrium, and kinetics)	4.53±0.74	3.50±0.50	5.00±0.00
2) The curriculum has prepared graduates to apply knowledge of earth science, a biological science, fluid mechanics	4.33±0.62	3.50±1.50	5.00±0.00
3) The curriculum must prepare graduates to			
3a) formulate material and energy balances	4.73±0.46	4.00±1.00	4.00±0.00
3b) analyze the fate and transport of substances in and between air, water, and soil phases	3.87±0.99	4.00±0.00	4.00±0.00
4) design environmental engineering systems that include considerations of			
4a) risk,	3.93±0.80	3.00±0.00	4.00±0.00
4b) uncertainty,	3.73±1.03	4.00±0.00	4.00±0.00
4c) sustainability,	4.00±0.65	4.50±0.50	4.00±0.00
4d) life-cycle principles,	4.00±0.53	3.50±0.50	4.00±0.00
4e) environmental impacts;	4.13±0.83	4.50±0.50	4.00±0.00
4f) apply advanced principles and practice relevant to the program objectives	3.93±1.16	4.5±0.50	4.00±0.00
5) The curriculum must prepare graduates to understand concepts of			
5a) professional practice	4.00±0.93	4.50±0.50	4.00±0.00
5b) project management	3.80±1.15	5.00±0.00	5.00±0.00
5c) the roles and responsibilities of public institutions and private organizations pertaining to environmental policy and regulations	4.13±1.06	5.00±0.00	4.00±0.00

* Rank (5-Strongly Agree; 1-Strongly Disagree)

Student rankings from the Likert scale and comments from both the survey and post-questionnaire highlight key outcomes addressed following completion of the capstone design course and outcomes that could have been addressed with more detail, better preparing them for their pending careers. Faculty ranking of outcomes reflects what they perceived was discussed and addressed during the capstone design course not necessarily the time allocated or thoroughness of how the outcomes were addressed throughout the course. Practicing engineer's rankings reflect a snapshot of student performance during the capstone design course. As stated through practicing engineers comments they advised students remotely, which did not allow them full understanding of concepts emphasized during the capstone design course. Below is a detailed breakdown of each student learning and curriculum outcome surveyed by students, faculty and practicing engineers.

Student Outcome 1

Students, faculty and practicing engineers ranked student outcome 1 with a 4.53, 4, and 5, respectively. The three evaluated groups perceived the outcome was addressed adequately during the capstone design course. The final written reports submitted at the completion of the design course illustrates students ability of applying knowledge of mathematics, science and engineering based on the proposed upgrades and preliminary design for the assigned WWTP.

Student Outcome 2

General observations by students, faculty and practicing engineers concluded that theory of design and interpretation of real plant data was perceived to be addressed. All three evaluating parties view economics as a weakness and not developed efficiently following completion of the design course EnvE 5305. Practicing engineers, comment below, view that with limited resources economic design is difficult to achieve in an academic setting ranking outcome 2a with a 2.

> *"This is difficult to accomplish in an academic environment, where access to current resources is limited"*

All three evaluating parties view social, political and ethical design constraints as being addressed minimally during the capstone design course. Students, faculty and practicing engineers rank outcome 2c with 3.13, 3.5 and 2, respectively.

> *"Ethical maybe [no political or social design]"*

> *"Nothing very controversial [with design prompt]"*

> *"Not really addressed"*

Additionally, practicing engineers commented that social, political and ethical design skills are further developed once practicing and dealing with municipalities.

> *"This is difficult to accomplish in an academic environment. Again, I wouldn't worry about the low score as this will be cultivated with actual practice."*

All parties disagree that the design course addresses manufacturability effectively. Students, faculty and practicing engineers ranked outcome 2e, manufacturability, 3.07, 2 and 3, respectively. Comments below discuss feedback of why rankings were given for outcome 2e.

> *"Construction costs and realistic implementation are hard to say"*
>
> *"Not main objective this semester and not really addressed"*
>
> *"I'm not quite sure what this means. Assuming that this is referencing "constructability," the class does do a good job of forcing the students to think with some of the constraints placed on an Engineer by a "real world" project."*

Student Outcome 2 was addressed through the cost analysis submitted as part of the final written report. Additionally, students were asked to perform preliminary designs for their proposed upgrades addressing the manufacturability and sustainability of their project. As part of the design selection criteria students were asked to address components of Student Outcome 2. Through responses from the survey it could be concluded that for future improvement of the course, more time should be spent on addressing engineering economics, social, political and sustainability as applied to designing upgrades to a WWTP. Student Outcome 2 was addressed through the capstone design course, but has room for improvement to better prepare students for their career.

Student Outcome 3

The three evaluating parties agreed, Student Outcome 3 was addressed based on student performance after completion of the first semester design course. Students, faculty and practicing engineers ranked Student Outcome 3 addressing the ability to identify, formulate and solve engineering problems with a 4.47, 4.5 and 5, respectively. Practicing engineers commented that outcome 3 is "o*ne of the stronger aspects of the class."*

Student Outcome 4

Students and faculty ranked Student Outcome 4 similarly with a 4.07 and 4, respectively. Both students and faculty agreed that Student Outcome 4 was addressed at the completion of the capstone design course commenting that through the project schedule, group evaluation and final submittals that professional and ethical responsibility was addressed. Practicing engineers neither agreed nor disagreed that the learning outcome was addressed during the course. Practicing engineers commented, "*Didn't see much emphasis on this [outcome] during my exposure to the class."*

Student Outcome 5

All three evaluating parties agreed that Student Outcome 5, the ability to communicate effectively, was addressed throughout the design course. Course components including the written report and final oral presentations allowed students to develop communications skills to effectively detail design of proposed upgrades for the treatment facility. Students conducted evaluations of the WWTP and communicated preliminary design upgrades for the assigned WWTP; therefore, addressing Student Outcome 5.

Student Outcome 6

Outcome 6 was ranked by students, faculty and practicing engineers with a 4.33, 4 and 5, respectively. Students commented that following completion of the design course they were beginning to think on a global scale when considering design upgrades to the WWTP. Students also commented that the course opened their eyes to the detail and consideration that needs to be made in a social, environmental and global context. Such consideration is documented in students written submittals and oral presentations.

Student Outcome 7

Student Outcome 7 asked the evaluating parties if recognition of the need for, and an ability to engage in life-long learning was addressed. Rankings varied for students, faculty and practicing engineers who responded with rankings of 4.33, 3.5 and 4, respectively. Faculty viewed student's performance not to fully recognize the need for life-long learning. Comments on student performance addressing outcome 7 are included below.

> *"Very important for aspiring engineers"*
>
> *"Definite realization for this class"*
>
> *"Recognition. Only in the context of new treatment technologies"*

Student Outcome 8

Students, faculty and practicing engineers agreed that the regional design prompt with additions such as odor pollution control and life-cycle analysis addressed Student Outcome 8. Students were made aware of contemporary issues and provided engineering upgrades as solutions. Rankings indicate that Student Outcome 8 was addressed through completion of course components such as the written report and oral presentation detailing design options and ultimately the selected upgrade proposed at the completion of the course.

Student Outcome 9

Students, faculty and practicing engineers ranked Student Outcome 9 with a 4.20, 3.5 and 5, respectively. Students commented that some newer technology was discouraged. Rankings and comments indicate that the course could improve by addressing Student Outcome 9 in more detail encouraging newer technologies, design techniques and modern engineering tools. Student Outcome 9 was addressed during students design selection and mass balance of the proposed upgraded WWTP reported in the final written report submitted at the end of the design course.

PSO1

Students, faculty and practicing engineers rank PSO 1 with a 4.53, 3.5 and 5, respectively. The evaluating parties agree that the capstone design course helps aid the students in addressing PSO 1. By performing a capacity analysis, mass balance and preliminary design calculations students utilize their knowledge of mathematics through calculus-based physics and chemistry. The final product of the course documents student use of mathematics during aforementioned tasks.

PSO 2

The three evaluating parties agree that throughout the semester, students are able to apply knowledge of biological science and fluid mechanics. Students build upon knowledge gained during pre-requisite courses and apply knowledge outlined in PSO 2 as documented in final reports submitted as part of the capstone design course components. Faculty commented that PSO 2 will be further addressed by the students once they calculate the hydraulic profile for the WWTP proposed upgrades during the sequential design course, EnvE 5306.

PSO 3

The three evaluating parties agree that PSO 3 was addressed by the completion of the capstone design course. Through the performance of a mass balance for the proposed WWTP rehabilitation, students addressed PSO 3a. The written report and oral presentation at the end of the course allowed for evaluation of how students performed for PSO 3a. An odor pollution task added to the WEAT design prompt by faculty ensured that students addressed the fate and transport of substances in and between air, water and soil phases (PSO3b).

PSO 4

PSO 4 breaks down into six subsections where the design of environmental engineering systems should address risk, uncertainty, sustainability, life-cycle principles, environmental impacts and apply advanced principles. Risk considerations were perceived by faculty and students to not be addressed by the completion of the design course. Students commented that not much consideration of risk was taken in the design and pre-requisite courses have not addressed the outcome sufficiently. Students commented that uncertainty was not a focus of design; therefore, not addressing PSO 4b by the end of the course. Faculty stated that some teams addressed uncertainty through their design selection presented in written reports. Life-cycle principles were addressed through an added task to the WEAT design prompt. The design selection task allowed for PSO 4b, 4c, 4d, 4e to be addressed. However, the rankings from the survey provide insight that students perceived PSO 4a, 4b and 4f could be strengthened within the capstone design course.

PSO 5

Students perceived the course did address PSO 5, but did not fully develop and enhance their project management skills ranking PSO 5b 3.8/5.

> *"This is thinking engineering project management in real world, a little better with resources would be helpful"*

> *"Not explicitly taught. Individual basis"*

Faculty and practicing engineers ranked project management with 5's strongly agreeing PSO 5b was addressed satisfactorily.

Students' questionnaire responses

Results from the open-ended responses from student questionnaires highlighted what students perceived as strengths and areas for improvement before and after completion of the first semester design course. Students perceived their strengths prior to completion of the design course to include knowledge of water/wastewater treatment technologies enhanced and developed through the MEnvE curriculum. Select students also viewed soft skills such as communication and time management as strengths. Areas for improvement students perceived included leadership and oral presentation skills. Below are responses students provided when asked to describe their strengths in areas related to their discipline (i.e. water wastewater, etc.).

> *"Currently working at [city, state] water reclamation center [and] have access to practical materials. Passionate about water and wastewater treatment"*

> *"Air pollution at this point has been my strength. I think that my strengths are entirely related to how interesting the course is."*

> *"Air, water, wastewater, R programming, statistical analysis, and oral presentation"*

> *"Knowledge of reuse for byproducts/co-products i.e. sludge, used process water and nitrification"*

A few student responses when asked to describe areas for improvement related to their discipline.

> *"Oral presentation"*

> *"Air pollution, MATLAB, R-programming"*

> *"Spreading out key parts of work among team members. I tend to take control and do the more difficult parts of a project on my own."*

> *"Biochemical kinetics, AutoCAD, PowerPoint and time management"*

Following completion of the first semester students described with greater detail areas for improvement highlighted based on performance and final products submitted for evaluation. Students responded that written communication skills were a key area for improvement following completion of the design course EnvE 5305. Time and project management were other areas for improvement students commented on and is an area they plan to focus on during the second semester of the capstone design course. Students were asked questions from Figure 2 regarding their perceived strengths and areas for improvement. Responses to how students described their strengths in areas related to their discipline are reflected below.

> *"Due to the curriculum, I have strengths in water and wastewater, air pollution, and groundwater contaminants."*

"Resource accumulation and cost analysis on treatment units, water flow and regulations."

"Working in a team, equalization basins, headworks and tertiary treatment"

Student responses when asked to describe areas for improvement related to their discipline after completing the first design semester.

"Meeting team deadlines and understanding the underlining processes in wastewater treatment"

"Writing as a whole and more specifically technical report writing. Improvements may be achieved by studying technical reports."

"I need to improve my organizational and time management skills"

<u>*Practicing engineers questionnaire responses*</u>

Responses from the questionnaire provided to practicing engineers highlights the strengths of the course and areas for improvement to better prepare students for careers in industry. When asked how the capstone design course prepared students for a career in industry practicing engineers responded with the following.

"By *my observation, the biggest benefit of the capstone class is that it forces the students to draw upon the body of knowledge that they have developed to-date and to apply that knowledge in a fashion that is not already pre-defined for them."*

Practicing engineers also provided feedback and suggestions for how the course could be improved to better prepare students for their careers.

"In lieu of having a few folks serve as general advisors to the class, I would suggest soliciting the help from additional practicing engineers. You could then have each of those individuals assigned to a specific team. They could arrange for a weekly Q&A session. I anticipate that each group would be more open and candid to ask questions if they do not have to do it in front of other groups."

<u>*Longitudinal study of capstone design course*</u>

A longitudinal study was performed based on the performance of students during the first semester design course, EnvE 5305, following the integration of the WEAT design competition prompt into the capstone design course for MEnvE students. Integration of the WEAT design prompt was first introduced during the 2011-2012 academic year. Data from the 2012-2013 academic years was not available and is not included in this study. Based on the performance of the final product submitted, grades averaged in the low A to B plus range. Table 7 provides averaged scores students received from faculty based on their final written report and oral presentation performance. General strength of student performance between the three years reported was their oral presentations. Written report grades reflect average performance and team project management as areas for improvement between most design course years. Students' project management skills as evaluated by faculty for the 2014-2015 academic year indicate that student performance improved compared to past design years. Better performance could be a reflection of additional attention faculty paid to effectively developing project management skills through implementation of project schedules and project updates.

Table 7: Faculty final evaluation averages of capstone design course following integration of WEAT problem statement

	Academic Year		
Factor	2011-2012	2013-2014	2014-2015
Total Written Report	87.2%	85.8%	87.1%
Total Presentation	96.5%	97.5%	95.3%
Total Project Management	54.3%	79.8%	89.7%
Final Project Grade	87.8%	89.9%	88.8%

Integration of the WEAT design prompt was new to TTU's environmental engineering design course and this paper reported how students, faculty and practicing engineers perceive ABET outcomes have been addressed since its integration into TTU's MEnvE program. Advisement from practicing engineers was added to the course beginning the 2012-2013 academic year. Practicing engineers serve as additional resources for the students and have been invaluable by providing students current practices and resources better preparing them for their careers. However, an improvement for the course would be to recruit additional practicing engineers to assign one per team. One on one advisement would allow practicing engineers to provide more specific instruction and provide detailed attention to student proposed designs.

As reported in this paper, students, faculty and practicing engineers agree that most ABET Student Outcomes and Program Specific Outcomes were addressed through the adaption of the WEAT design prompt. The WEAT design prompt and added course tasks of odor pollution control addressed Program Specific Outcomes and specific Student Outcomes as well as encouraged an environment for problem-based learning. However, through the Likert survey of ABET Outcomes, this study highlights areas of the course that could be improved to better address all desired Learning Outcomes. Economics, risk assessments, social and political impacts of upgrades could be emphasized more as part of the proposed design. Additionally, newer technologies could be more encouraged by providing additional manufacturer and pilot study resources for the students to explore. Overall, ABET Outcomes were being achieved through current components of the course as perceived by students performance when evaluated by students, faculty and practicing engineers.

Conclusion

Students, faculty and practicing engineers offer varying perceptions on student performance in a capstone design course. ABET accreditation requires student development and enhancement through course work meeting Student and Program Specific Outcomes. Practicing engineers offer additional guidance for students preparing and enhancing student skills for their careers. Student technical performance was perceived as strengths by all three evaluating parties. Project management skills were perceived weak by students; however, both faculty and practicing engineers perceived such skills were adequately addressed during the design course. Economic analysis, ethical, political and social designs were perceived by all evaluating parties to not be addressed thoroughly throughout the capstone design course and are areas for course improvement. Students responded to questionnaires providing self-evaluation of strengths and areas for improvement before and after completion of the capstone design course. Students stated technical skills were further enhanced following completion of the design course while it was highlighted that report writing, time and project management skills were areas for improvement of student performances. Generally, students, faculty and practicing engineers feedback agreed that ABET outcomes were addressed when utilizing the design competition prompt. Integration of the WEAT design competition problem with the capstone design course provided students an opportunity to enhance communication and technical skills preparing them for a successful career.

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