Assessing Sustainability in Design in an Infrastructure Course through Project-Based Learning

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Abstract

The United States Military Academy (USMA) seeks to educate and inspire their civil engineering students through a rigorous and realistic academic program. One of the introductory courses in the civil engineering program is a broad-based infrastructure engineering course that incorporates multiple engineering disciplines. The course exposes students to foundational concepts like landfill operations, conventional water treatment methods, electrical transmission and distribution, and traffic flow theory, while being adaptable enough to field more contemporary issues as well. A recent contemporary issue addressed in the course is sustainability in design, one of the newest curriculum criteria established by the Accreditation Board for Engineering and Technology (ABET) for civil engineering programs.

The purpose of this paper is to propose a way of integrating and assessing the new ABET civil engineering program curriculum criteria of sustainability in design, specifically through the assessment of a project-based learning experience in an infrastructure engineering course. The project consists of an investigation and assessment of a proposed site with existing infrastructure as a potential base of operations in the aftermath of a catastrophic event. This paper outlines the scope of the culminating project, which includes a summary of the students’ findings via an executive summary, briefing, and oral exam. A threefold assessment is presented with respect to the course objectives, department mission to educate and inspire, and the civil engineering program student outcomes.

Introduction

The mission of the United States Military Academy (USMA) has evolved since the institution’s inception in 1802:

To educate, train, and inspire the Corps of Cadets so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country, and prepared for a career of professional excellence and service to the Nation as an officer in the United States Army.

The Department of Civil and Mechanical Engineering is one of 11 departments at the Academy, and both the civil and mechanical engineering programs are accredited by the Accreditation Board for Engineering and Technology (ABET). The mission of the Department of Civil and Mechanical Engineering parallels the Academy’s mission, while focusing on educating and inspiring students in the fields of civil and mechanical engineering:

To educate, develop, and inspire agile and adaptive leaders of character who design and implement innovative solutions and win in complex environments as trusted Army professionals.

The civil engineering program established 16 student outcomes to achieve the mission and meet the ABET accreditation requirements, four of which pertain to the assessment of the course project discussed in this paper:

2. Demonstrate creativity, in the context of engineering problem-solving.
6. Function effectively on multidisciplinary teams.
10. Speak effectively.
11. Incorporate knowledge of contemporary issues into the solution of engineering problems.

Recognizing that the Department’s mission statement includes educating and inspiring, the civil engineering faculty have sought to develop their program appropriately along a set of commonly accepted educational taxonomies; that is, Bloom’s Taxonomy. These widely known taxonomies are based on the seminar work of the 1950’s educational committee chaired by Benjamin Bloom. The committee established a set of taxonomies in three domains of learning: cognitive, affective and psychomotor. The cognitive domain taxonomy is widely accepted in many fields and has been identified as, “arguably one of the most influential education monographs of the past half century.” The taxonomies are a language that describes the progressive development of an individual in each domain and are defined as follows:

- Cognitive: of, relating to, being, or involving conscious intellectual activity.
- Affective: relating to, arising from, or influencing feelings or emotions.
- Psychomotor: of or relating to motor action directly proceeding from mental activity.

A set of development levels for each domain are shown in Table 1 based on work by Bloom, Krathwohl et al., and Simpson, respectively. Each column shows the levels in each domain, from the simple at the top, to the more complex at the bottom.

<table>
<thead>
<tr>
<th>Cognitive Domain</th>
<th>Affective Domain</th>
<th>Psychomotor Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Receiving</td>
<td>Perception</td>
</tr>
<tr>
<td>Comprehension</td>
<td>Responding</td>
<td>Set</td>
</tr>
<tr>
<td>Application</td>
<td>Valuing</td>
<td>Guided Response</td>
</tr>
<tr>
<td>Analysis</td>
<td>Organization</td>
<td>Mechanism</td>
</tr>
<tr>
<td>Synthesis</td>
<td>Characterization by a</td>
<td>Complex Overt Response</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Value Complex</td>
<td>Adaptation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Origination</td>
</tr>
</tbody>
</table>

The authors recognized that their institutional and department mission statement expects both education (cognitive domain) and inspiration (affective domain) in their program. Furthermore, the authors believe that the engineering education profession is setting an expectation for student development in both of these domains. In particular this trend is evident in the American Society of Civil Engineers (ASCE) Body of Knowledge 2 (BOK2) and has been studied in detail by the [Hanus] author. As such, courses in the Academy’s civil engineering program strive to develop their students in both domains.

The purpose of this paper is to propose a way of integrating and assessing the new ABET civil engineering program curriculum criteria of sustainability in design, specifically through the assessment of a project-based learning experience in one of the civil engineering program’s courses (CE350 – Introduction to Infrastructure Engineering) at the United States Military Academy. The project consists of a reconnaissance and evaluation of a proposed site with existing infrastructure as a potential base of operations in the aftermath of a catastrophic event.
The students are required to provide a brief overview of their findings via an executive summary, briefing, and oral exam. Students must defend their assessments and propose feasible design alternatives in light of discovered site shortcomings, particularly by considering the principles of sustainability in design in their analysis. A threefold assessment is presented with respect to the course objectives, department mission to educate and inspire, and the civil engineering program student outcomes.

**Literature Review**

While sustainability is not a new idea, it has been gaining prominence in the educational community in the last few decades. Recently, the concept of sustainability has been integrated into the student and curriculum outcomes as described by the ABET Program Criteria for Civil Engineering Programs. The criteria for the 2016-2017 accreditation cycle includes several mentions of sustainability from previous cycles, but has only recently incorporated the addition of “sustainability in design” for Civil Engineering Program Curriculum criteria:

- “The curriculum must prepare graduates to … design a system, component, or process in at least two civil engineering contexts; include principles of sustainability in design…”

For the Civil Engineering Discipline, ABET relies on the input of the American Society of Civil Engineers (ASCE). ASCE defines sustainability as “A set of environmental, economic and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality or availability of natural, economic, and social resources” and this is the definition the authors have adopted for this paper. ASCE recognizes the growing importance of students to understand problems’ and solutions’ impact across the three pillars of economic growth, environmental stewardship, and social progress. The multi-dimensional analysis allows students to better assess the complexity of the application of the knowledge they learn. The concept of sustainability even appears in the Civil Engineering Code of Ethics as one of the Fundamental Cannons that “Engineers shall…strive to comply with the principles of sustainable development…” yet more evidence that sustainability is becoming a foundational and essential component of an engineering education.

Given the importance of sustainability in civil engineering curricula, an important question remains: how do we teach it? One method discussed in this paper is the Problem-Based Learning (PBL) approach. Problem-Based Learning is defined as “focused, experiential learning organized around the investigation, explanation, and resolution of meaningful problems” by Hmelo-Silver. Hmelo-Silver also showed that PBL is suited “for engineering programs for students to engage in complex, ill-suited, and open-ended problems to foster flexible thinking and support intrinsic motivation.” That makes it a viable candidate for questions related to sustainability due to the complexity of such problems caused by the interrelationships between the pillars through time.

Use of PBL to solve ill-defined, complex problems encourages students to demonstrate higher levels of Bloom’s cognitive domain, as demonstrated in Table 1, such as analysis and synthesis. In many ways, PBL is very similar to Experiential Learning Theory (ELT). A. Kolb and D. Kolb define ELT as the “process whereby knowledge is created through transformation of experience.
Knowledge results from the combination of grasping and transforming experience.¹⁸ Figure 1 below shows the Experiential Learning Cycle.

![Image of Experiential Learning Cycle]

**Figure 1: The Experiential Learning Cycle¹⁹**

In this way, students are able to learn from both their actual personal experiences, what Kolb calls experience in a concrete fashion, and through simulations, what Kolb calls abstract conceptualizations.¹⁸ Given a problem to which a student can relate to from their own past personal experiences as well as simulating a potential future event, allows PBL and ELT to work together.

Furthermore, ELT instruction can be recognized by analyzing the student engagement with the problem presented. Anderson identified a few indicators of ELT instruction:

- Students engaged in EBL are involved through their senses, feelings, and intellect, at varying levels.
- Students can recognize and relate lessons to personal learning experiences.
- Students can reflect upon earlier experiences and transform them into deeper understanding.²⁰

Therefore, given the complex nature of sustainability problems and the PBL and ELT pedagogy, realistic problems that draw on students’ past experiences may be an effective way to meet the ASCE and ABET goals as it pertains to teaching sustainability in design to engineers.

**Sustainability in Design within the Course and Final Project**

**Course Scope, Objectives, and Structure.** The CE350 – Infrastructure Engineering²¹-²³ course has six primary objectives:

1. Identify, assess, and explain critical infrastructure components and cross-sector linkages at the national, regional, and municipal levels
2. Calculate the demand on infrastructure components and systems
3. Assess the functionality, capacity, and maintainability of infrastructure components and systems
4. Evaluate infrastructure in the context of military operations
5. Prioritize and recommend actions to improve infrastructure resilience
6. Apply the principles of sustainability in design to infrastructure components and systems.

The course is decomposed into five different blocks of instruction. The first presents the general concepts of infrastructure systems through discussions on network theory, infrastructure modeling, and stakeholder analysis. The next few blocks introduce three of the primary infrastructure systems in our society today: water and wastewater, energy, and transportation. The final block orients the students to the military applications of infrastructure engineering. Threaded throughout the entire course, as well as the final project, is the concept of sustainability in design of infrastructure. The project, discussed below, is executed at the end of the semester.

**Infrastructure Reconnaissance Project.** The CE350 infrastructure reconnaissance project outlines the need for students to conduct a detailed reconnaissance and assessment of a specified location as a potential base of operations in the aftermath of a catastrophic event. The proposed site has existing infrastructure, such as water and wastewater treatment plants, solid waste disposal, and emergency generators. The incoming population includes local and state responders totaling approximately 1000 people. The project groups must apply their knowledge of infrastructure systems and assess the current capacity of the site against the demands of the incoming population. Upon completion of their analysis, the students should realize that the water treatment plant cannot provide enough potable water, the wastewater treatment plant is unable to treat the anticipated sewage generated by the population, space might be an issue depending on their site layout for vehicle parking and bed down areas, and the solid waste management plan needs to be adjusted. The fall 2016 term (17-1) consisted of 54 students, where the project was completed in groups of 4-5 students. The project itself has three graded portions:

1. **Executive Summary.** The course instructor provides the groups with the project’s scenario, detailed submission requirements, and affords groups over two hours to reconnoiter the proposed site’s existing infrastructure. The groups compile a table quantitatively summarizing the capacity of each infrastructure system on site (i.e., water, wastewater, solid waste, electrical power, fuel, transportation, billeting, and security) against the anticipated incoming population’s demand of each system. Furthermore, the groups provide overlays for their proposed site layout to utilize the existing infrastructure. Based on their findings, each group delivers their recommendation on whether or not the site is suitable for the incoming population, as well as sustainable design alternatives that feasibly address the site’s shortcomings.

2. **Briefing.** After the executive summary submission, each group provides a ten minute briefing to the instructor on the results of their analysis. The briefing is not only a platform for the group’s formal presentation of their findings and recommendations, but it also provides each group member the opportunity to effectively articulate a summary of their work to an audience.

3. **Oral Exam.** The instructor then asks questions to all members of the team to assess their understanding of the overall project, giving them the opportunity to defend their assessments and proposed design alternatives, as well as consider options concerning sustainability in their site assessment. Questions pertaining to sustainability in design test
the student’s understanding of the topic while achieving higher levels of Bloom’s
taxonomy, namely, formulating a proposed design to a given scenario. Since each project
group should conclude that the site is inadequate in the areas discussed above, particular
emphasis is placed on the students’ proposal of sustainable design alternatives. These
alternatives include either changing people’s behaviors to reduce the usage of the
infrastructure system of interest, implementing more efficient technologies, or integrating
renewable or regenerative processes.

Final Project Assessment

The assessment of the project is considered with respect to the CE350 course objectives, the
department mission, and the civil engineering program student outcomes.

Assessment of Course Objectives. Course objectives are assessed annually as part of the civil
engineering program’s course assessment process. Course directors apply a standardized rubric
based on student performance on graded requirements as shown below. The definition of
“meeting a course objective” is achieved by a “C” level (70%) on the graded requirement.

1= Objective Not Met. Most (75%) of the students did not achieve it.
2= Objective Marginally Met. Objective met by half the students or minimally by most.
3= Objective Satisfactorily Met. Objective clearly met by a majority (70%) of the students.
4= Objective Solidly Met. Objective clearly met by the vast majority (90%) of students.
5= Objective Clearly Met. All students achieved the objective.

The assessment of the final project for the fall academic term in 2016 is shown below in Table 2
and demonstrates that the related course objectives were clearly met by all the students. The
overall project average was 89.8%. In the CD assessment column, the course director evaluated
the extent to which each respective course objective was met with reference to the students’
performance on the infrastructure reconnaissance project. In each case, the objective was clearly
met, meaning that all the students in the course achieved at least a 70% grade on the project’s
requirements.

Table 2. Fall 2016 (17-1) Assessment of Final Project against the CE350 Course Objectives.

<table>
<thead>
<tr>
<th>Course Objectives Related to Final Project</th>
<th>CD Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Calculate the demand on infrastructure components and systems</td>
<td>5</td>
</tr>
<tr>
<td>3. Assess the functionality, capacity, and maintainability of infrastructure components and systems</td>
<td>5</td>
</tr>
<tr>
<td>4. Evaluate infrastructure in the context of military operations</td>
<td>5</td>
</tr>
<tr>
<td>5. Prioritize and recommend actions to improve infrastructure resilience</td>
<td>5</td>
</tr>
<tr>
<td>6. Apply the principles of sustainability in design to infrastructure components and systems</td>
<td>5</td>
</tr>
</tbody>
</table>

Assessment of Department Mission: Indirect indicators, such as anonymous student course end
feedback, are also used to assess the course, particularly with regard to the department mission,
“To educate cadets in civil and mechanical engineering, such that each graduate is a
commissioned leader of character who can understand, implement, and manage technology; and to inspire cadets to a career in the United States Army and a lifetime of personal growth and service.”

Students in the course answer 11 common questions in a mandatory course-end feedback system and results from the course (CE350) are compared to historical course-end feedback data for the purposes of annual course assessments. Figure 2 illustrates that since the course incorporated sustainability in design into the final project in 17-1, positive feedback increased noticeably compared to the previous semester in 16-1. Of note, students in CE350 reported that their “motivation to learn and to continue learning increased” and their “critical thinking ability increased” at a higher rate than the previous semester students.

![Historical Feedback, USMA Questions](image)

**Figure 2. Historical Course-End Feedback for CE350**

Furthermore, the students provided overwhelmingly positive remarks to the future utility of the course in their careers, such as:

- “I think the knowledge covered here will be useful in my future career.”
- “Knowledge of infrastructure helps me better understand how the world works.”
- “I think that this course will help me in my Army career. The knowledge that will be the most useful will be coming up with creative and effective solutions to a problem.”
“I think the knowledge will be helpful because it will my make decision-making better. I think the knowledge will be important when developing a living area or working with locals.”

“Knowing critical infrastructure especially proved invaluable during this semester already. During my interactions with other militaries and countries, I needed to know what capabilities they need and care about.”

Overall, the authors feel that the development of the course’s final project to incorporate and assess the new ABET civil engineering program curriculum criteria of sustainability in design served to impact the cognitive development of the students by educating them in creative and innovative ways to develop sustainable design alternatives in infrastructure problems. In addition to the sustainability topics discussed throughout the semester in each block, the course also assessed student’s understanding of and ability to apply these principles in a project-based learning experience. The assessment focused on the level of achievement of course objectives, particularly in applying principles of sustainability in design. The assessment above displays clear achievement of each course objective. The authors also feel the course impacts their affective development, while also contributing to the mission accomplishment of the Department of Civil and Mechanical Engineering and inspiring our future engineers. Based on the course end feedback, the students were clearly inspired by the material they learned throughout the course. Furthermore, the students displayed achievement of higher levels of both the cognitive and affective domains. Particularly within the context of the project, the students demonstrated achievement of analysis and evaluation in their assessments, recommendations, and proposals of feasible sustainable design alternatives. Moreover, the students exhibited an internalizing of the values of sustainability in design, moving beyond simply providing feasible solutions satisfying to the instructor but in revealing a desire for continued growth in the discipline and future application of the principles in their careers following graduation. In addition to the assessment of sustainability in design in the final project with respect to the course objectives and the department mission, the authors also conducted this assessment with respect to the program student outcomes.

Assessment of Civil Engineering Program Outcomes: There were four Civil Engineering ABET Program Outcomes that were assessed with respect to the project presented in this paper:

2. Demonstrate creativity, in the context of engineering problem-solving.
6. Function effectively on multidisciplinary teams.
10. Speak effectively.
11. Incorporate knowledge of contemporary issues into the solution of engineering problems.

The 2nd outcome, Demonstrate creativity, is directly related to the project as result of the expectation for students to develop creative solutions to the infrastructures challenges with consideration for sustainability. The 6th outcome, Function effectively on multidisciplinary teams, is included because the infrastructure problems include both engineers and non-engineers alike, such as politicians, military leaders, and lawyers. This wide array of disciplines is representative of the population taking the course, since it is both a part of the civil curriculum and a track requirement for many non-majors. The 10th outcome, Speak effectively, is assessed relative to the student’s briefing requirement. And the 11th outcome, Incorporate knowledge of contemporary
issues, is incorporated with the assessment because of the recognition that sustainability is of a growing interest in our civil engineering profession.

The assessment of the outcomes associated with the project in this course represent just a portion of the overall assessment process utilized in the Civil Engineering ABET Program Assessment. Similar to the assessment of the course objectives discussed above, the student outcomes were assessed for the project and the results are presented in Table 3. For the assessment, considerations were given to the uniqueness of the proposed student solutions (Outcome #2), observed effectiveness of the student project teams (Outcome #6), quality of the student briefings (Outcome #10), and relative incorporation of feasible sustainability solutions to the determined site shortcomings (Outcome #11). The results of the assessment display that the related course objectives were solidly met by at least 90% of the students for Outcomes #2 and #6 and clearly met by all the students for Outcomes #10 and #11. As mentioned earlier, the overall average grade for the project was 89.8%. The assessment of the student outcomes is particularly oriented towards the achievement of higher levels of Bloom’s taxonomy, meaning that the students’ grades were not just based on comprehension and application of the principles of sustainability in design, but their project submissions were assessed based on their ability to synthesize all the course material and evaluate feasible, unique solutions to a complex engineering problem by incorporating knowledge of sustainability in design. Consequently, the authors feel the incorporation of the ABET civil engineering program curriculum criteria of sustainability in design within the final project scenario served in the achievement of the four program outcomes outlined in Table 3.

### Table 3. Fall 2016 Assessment of Final Project against Civil Engineering Program Outcomes

<table>
<thead>
<tr>
<th>Program Outcomes</th>
<th>Assessment*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. <em>Demonstrate creativity, in the context of engineering problem-solving.</em></td>
<td>4</td>
</tr>
<tr>
<td>6. <em>Function effectively on multidisciplinary teams.</em></td>
<td>4</td>
</tr>
<tr>
<td>10. <em>Speak effectively.</em></td>
<td>5</td>
</tr>
<tr>
<td>11. <em>Incorporate knowledge of contemporary issues into the solution of engineering problems.</em></td>
<td>5</td>
</tr>
</tbody>
</table>

*Note: See the Assessment of Course Objectives section above for the description of the assessment ratings given in the right-hand column.*

### Conclusion and Future Work

The recently updated ABET civil engineering program criteria now includes sustainability in design. The purpose of this paper was to propose a way of integrating and assessing this new program criteria within a civil engineering course, where the students’ understanding of the topic was assessed through a project-based learning experience. Using this method to incorporate and assess this new ABET program outcome successfully demonstrated a higher level understanding of the sustainable concepts taught in the course. It also served in inspiring the students to develop creative and innovative ways to integrate sustainable design alternatives in infrastructure problems. The project effectively facilitated a deeper cognitive and affective understanding of sustainability in design. Not only did the authors see an increase in student performance but the
students also gained a more favorable outlook on the application of this knowledge in their future career fields. It is the authors’ hope that the civil engineering academic community would build upon the proposal and findings of this paper to implement and assess the new curriculum criteria.

In light of the findings in this paper, the authors are systematically integrating sustainability in design throughout the different blocks of instruction in the course to demonstrate how infrastructure problems cannot be properly addressed without consideration of the topic of sustainability. The goal is not to think about sustainability as a separate sub-discipline but rather a necessary design consideration in any process or project. Lectures have been added that address sustainability in the water, energy, and doctrine/policy blocks. On a wider scale, the program as a whole has likewise taken steps to integrate sustainability throughout the entire civil engineering program curriculum. In addition to the Infrastructure Engineering course, it is currently addressed in Hydrology and Hydraulic Design, Construction Management, Civil Engineering Site Design, as well as the Senior Capstone Project. Due to the pervasiveness of the topic throughout the curriculum, civil engineering majors have shown heightened interest in sustainability in civil engineering. The program has seen a 22% increase in the independent study elective that prepares students to take the Leadership in Energy and Environmental Design (LEED) Green Associate exam and Envision Sustainability Professional exam since the first course offering in 2013.
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