Building Bridges – Spanning the gap between the classroom and professional practice

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One of the ABET Inc. civil engineering program requirements is for the curriculum to prepare graduates to design a system, component, or process in at least two civil engineering contexts. Additionally, ABET Inc. requires the curriculum to include a culminating major engineering design experience that incorporates appropriate engineering standards and multiple constraints, and is based on the knowledge and skills acquired in earlier course work. While there are various ways to accomplish these requirements, many programs use a capstone design project or experience. The paper outlines how the civil engineering program at the United States Military Academy (USMA) uses a real-world design-build project that requires students to engage with multiple stakeholders, design a bridge with several constraints, and then construct the bridge. The paper outlines the entire capstone process from conception to completion, with emphasis on problem definition, development of alternatives, interactions with stakeholders, designing under real constraints, construction, and project management. The design-build capstone provides an authentic and exciting design challenge that motivates students and promotes their learning and development as engineers.

Introduction

The mission of the United States Military Academy (USMA) has evolved since the institution's inception in 1802[1]:

To educate, train, and inspire the Corps of Students 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 13 departments at the Academy, and both the civil and mechanical engineering programs are accredited by ABET Inc. 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[2]:

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 is aligned with the seven ABET[3] student outcomes found in Criterion 3 (Student Outcomes) to achieve the mission and meet accreditation requirements:

Our students upon graduation:

1. *an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics*
2. *an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors*
3. *an ability to communicate effectively with a range of audiences*
4. *an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts*
5. *an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives*
6. *an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions*
7. *an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.*

In addition to the student outcomes, ABET Criterion 5 (Curriculum) states that the curriculum must include a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work. The curriculum must also meet civil engineering program criteria that include designing a system, component, or process in at least two civil engineering contexts.

The capstone course, which spans two semesters, serves as this culminating major engineering design experience at the USMA. CE493 (Civil Engineering Capstone Design I) occurs in the fall and CE494 (Civil Engineering Capstone Design II) occurs in the spring. Each course is worth 3.5 credit hours, and has the following objectives:

1. Function as part of a multi-disciplinary team.
2. Apply the civil engineering design process and conduct iterative analysis and design of a solution to a challenging, ill-defined and open-ended problem.
3. Design a system, component, or process in more than one civil engineering context in accordance with applicable codes and regulations.
4. Incorporate contemporary issues, such as economic, environmental, social, political, ethical, health and safety, manufacturing, and sustainability, as applicable into the into the solution of an engineering problem.
5. Communicate and justify an engineering design through oral and written form.

The focus of this paper is how the USMA civil engineering program uses a real-world design build bridge project to meet the ABET requirements and support the department's mission. This type of project is one of several types the USMA civil engineering program pursues each year.

Literature Review

Using a real-world project is not unique to the USMA, as other have outlined how such projects are well suited to meet the ABET requirements.

Howe and Wilbarger[4] conducted a survey of engineering capstone courses in the United States to gain an understanding of how they were structured. Their research found that most capstone courses contained a mixture of classroom and project components, with an increase in both the variety and quantity of projects that were externally sourced through industry.

Hunt and Detloff[5] conducted a case study of an interdisciplinary capstone engineering design and outlined how it was associated with the recently revised ABET student outcomes (1 through 7).

Padmanabhan et al[6] describes how North Dakota State University has recently refined their capstone course experience to use real-world projects that integrate students, faculty, and practicing professionals.

CE493/4 – Civil Engineering Capstone Design I & II (Design Build Project)

Project Background: Fahnestock State Park is located on the east side of the Hudson River near Cold Spring, NY, and about thirty minutes away from West Point. Several of the bridges were washed out or damaged during Hurricane Sandy in 2012. Some of the bridges were replaced with temporary structures or left in a degraded state. The state park contacted the USMA civil engineering program in 2016 to inquire about the possibility of assisting with repairing or replacing the bridges as part of a student project. The USMA civil engineering program is currently in its fourth year of designing and building a bridge as one of the capstone design project options. While each bridge was unique in terms of its specific location within the park, the bank conditions and required span, and its intended use, this paper will focus on the general processes that were common to all the projects. Each project required Students to design, model, and construct a multi-use bridge, while considering key stakeholder requirements, sustainability considerations, building codes, and environmental constraints. The project teams have included 8-10 Students and have had the following overarching objectives:

- Conduct stakeholder analysis to identify the needs/wants of the stakeholders, primarily the Fahnestock State Park management team, the Taconic Region of NY State Parks, and the Open Space Institute.
- Conduct site reconnaissance to gather pertinent information pertaining to the project.
- Develop four to six feasible conceptual designs.
- Fully design two bridge options (generally 4-5 Students on each design team); includes all technical design aspects, along with a computer model and cost estimate.
- Obtain construction permit, which requires environmental approval.
- Procure all building materials.
- Develop construction schedule.
- Construct bridge.
- Present results during USMA Projects Day.

Project Process: This portion of the paper describes how the design build projects are conducted throughout the academic year.

Project Selection: Students provide input during the spring of their junior year into the type of capstone project they would like to conduct during their senior year. The capstone design course director, in conjunction with other faculty, develops a slate of several project options based on student interest. All projects must meet the ABET requirements of is developed based on their interests. All projects are real-world, that is, they are not notional projects simply for an academic purpose. Projects are based primarily on the knowledge and skills acquired in earlier course work, although they often require students to acquire some new knowledge or skills as well. Lastly, projects require students to incorporates appropriate engineering standards and consider various constraints in the design process. Students are presented the specific capstone project options on the first lesson of CE493 in the fall of their senior year. There are generally eight to ten project options that 35-45 civil engineering majors can choose from. Students are asked to provide their top four preferences. There are generally 8-10 Students on the bridge design build projects, and the project has been the first or second choice for all of them during each of the four years doing this type of project. For those who listed it as their second choice, they had listed a smaller scope design build project as their first choice. Overall, every Student selected this type of project for their culminating capstone project.

Team Organization: The team organized itself as a design build firm with the understanding that the team would need to fully design two distinct bridges as part of the course. The group often split into two design teams during the fall semester as one of the requirements was to fully design two distinct bridge options.

Conceptual Designs: The specific requirements for the project were initially left ill-defined, causing students to collaborate with the stakeholders and project advisors. The project team met with the stakeholders early in the semester to determine the specific needs and constraints of the project. One of the recent bridges had a requirement to span 26 feet and be capable of accommodating pedestrians, equestrians, and a 5-ton vehicle. The team also conducted a reconnaissance of the site to obtain specific measurements of the existing bridge, conduct a survey of the site including the bank and stream profiles, and to develop an appreciation for site access. Figure 1 below (intentionally redacted) shows the condition of one of the bridge abutments and Students conducting a site survey.

Figure 1: Site Reconnaissance and Survey

Students developed four to six conceptual design concepts based on the stakeholder input and site reconnaissance. The concepts were presented to the stakeholders, and the stakeholders were asked to select two concepts they would like to see fully designed.

100% Designs: The team fully designed two bridges during the remainder of the fall semester. Each design contained three subdisciplines of civil engineering. Teams designed the bridges in accordance with the LRFG Guide Specifications for the Design of Pedestrian Bridges and in consultation with the regional State Park Engineer. Geotechnical analyses were conducted and used in the design of the footings for the bridge. Live, snow, and self-weight loads were analyzed as part of the structural analysis and incorporated into the design of the bridge. Teams designed the footings and associated formwork, structural elements of the bridge, the decking, and the railings for the bridge. They also evaluated the watershed area and discussed historical flows with members of the Park staff and the regional Natural Resource Steward Biologist to ensure the new bridge was at an appropriate elevation. They used the 100-year storm and the rational method for their analysis. In each case, the bottoms of the bridges were raised approximately 18 to 24 inches from their original elevation to reduce the potential for them to be impacted by floods. Additionally, the increase in elevation placed the bridge at a higher elevation than nearby areas such that if the water exceeded the stream banks, it would flood the surrounding area and flow over the trail itself prior to impacting the bridge. Applicable codes and regulations such as the National Design Specification for Wood Construction, ACI 318, the AISC Manual of Steel Construction, and NY Building Codes were used, and each design also included a computer model and cost estimate. Figure 2 shows two models for one of the bridges.

Figure 2: Models of two bridge design options

The stakeholders were presented both designs, along with their estimated cost, toward the end of the fall semester and were asked to select which option they would like constructed. The design and supporting calculations for the selected option were then submitted to the NY State Park Engineers office for review and approval of a building permit. The design also involved environmental and historical considerations, which were part of the permitting process.

Material Procurement and Construction: The spring semester was focused on obtaining a construction permit, so there is often dialog with the NY State Park engineer to clarify any questions pertaining to the design. The team also validated a list of materials and coordinated to have everything procured by the Open Space Institute[7], an organization that works with NY State Parks to make significant park improvements by expanding and easing access to nature through recreational facilities, trails, visitor centers, and interpretive programming. The Open Space Institute provided funding for all materials, and all labor is “donated” by the students. The team prefabricates some portions of the bridge on campus in a laboratory environment but completed most of the construction on site. Construction related activities have taken 700-900 labor hours for these projects. Figure 3 shows images of the bridges constructed during the past three years.

2016-2017 2017-2018 2018-2019

Figure 3: Images of bridges from past three years

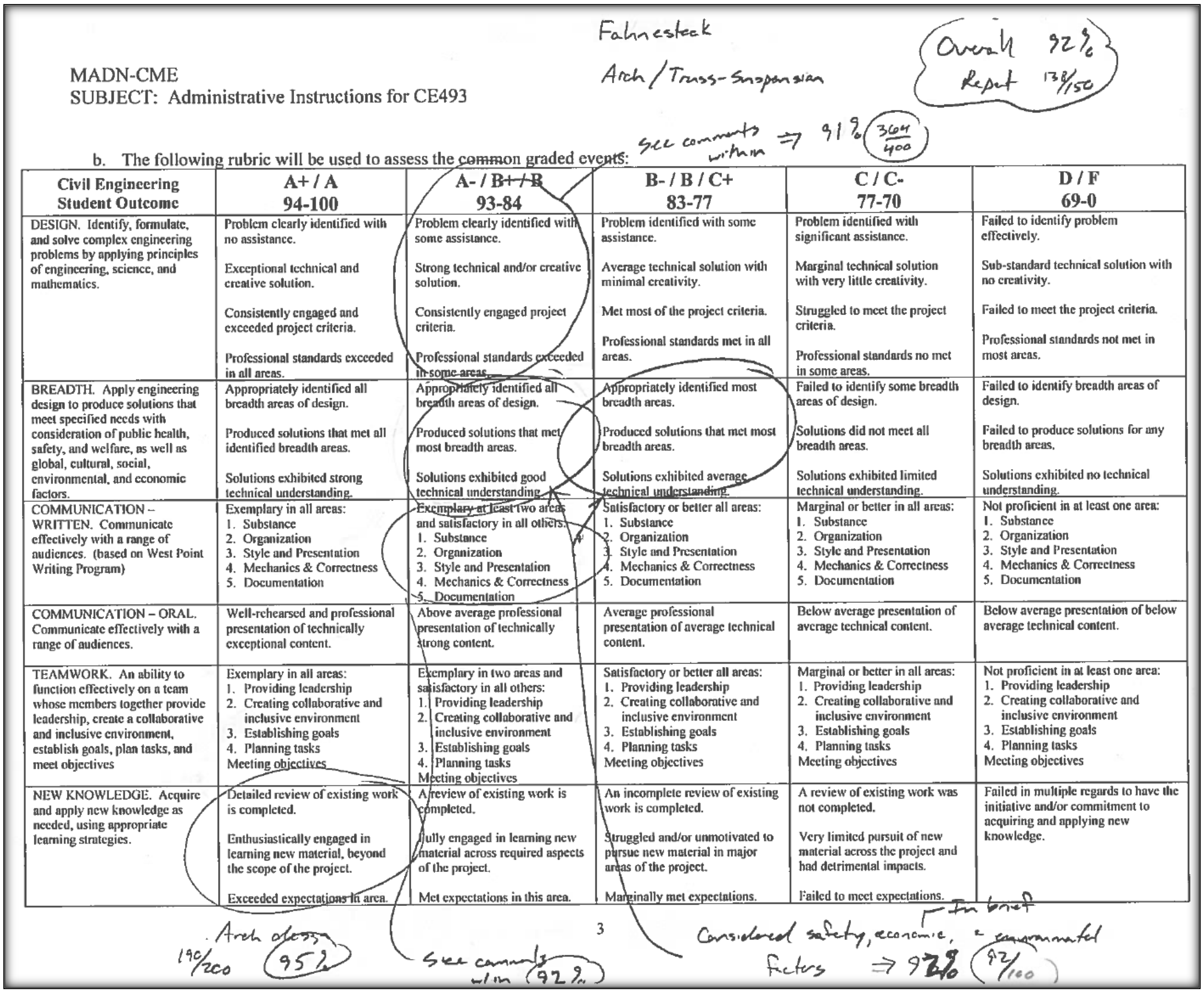
Assessment

The assessment of the project was considered with respect to the CE493 and CE494 course objectives and the civil engineering program student outcomes. The rubric in Table 1 below was used to assess student outcomes 1, 2, 3, 5, and 7.

Table 1: Rubric to assess student outcomes

Civil Engineering Student Outcome	A+ / A 94-100	A- / B+ / B 93-84	B- / B / C+ 83-77	C / C- 77-70	D / F 69-0
DESIGN (SO1): Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	Problem clearly identified with no assistance. Exceptional technical and creative solution. Consistently engaged and exceeded project criteria. Professional standards exceeded in all areas.	Problem clearly identified with some assistance. Strong technical and/or creative solution. Consistently engaged project criteria. Professional standards exceeded in some areas.	Problem identified with some assistance. Average technical solution with minimal creativity. Met most of the project criteria. Professional standards met in all areas.	Problem identified with significant assistance. Marginal technical solution with very little creativity. Struggled to meet the project criteria. Professional standards no met in some areas.	Failed to identify problem effectively. Sub-standard technical solution with no creativity. Failed to meet the project criteria. Professional standards not met in most areas.
BREADTH (SO2): Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.	Appropriately identified all breadth areas of design. Produced solutions that met all identified breadth areas. Solutions exhibited strong technical understanding.	Appropriately identified all breadth areas of design. Produced solutions that met most breadth areas. Solutions exhibited good technical understanding.	Appropriately identified most breadth areas. Produced solutions that met most breadth areas. Solutions exhibited average technical understanding.	Failed to identify some breadth areas of design. Solutions did not meet all breadth areas. Solutions exhibited limited technical understanding.	Failed to identify breadth areas of design. Failed to produce solutions for any breadth areas. Solutions exhibited no technical understanding.
COMMUNICATION – WRITTEN (SO3): Communicate effectively with a range of audiences. (based on West Point Writing Program)	Exemplary in all areas: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Exemplary at least two areas and satisfactory in all others: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Satisfactory or better all areas: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Marginal or better in all areas: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Not proficient in at least one area: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation
COMMUNICATION – ORA (SO3) Communicate effectively with a range of audiences.	Well-rehearsed and professional presentation of technically exceptional content.	Above average professional presentation of technically strong content.	Average professional presentation of average technical content.	Below average presentation of average technical content.	Below average presentation of below average technical content.
TEAMWORK (SO5): An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	Exemplary in all areas: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Exemplary in two areas and satisfactory in all others: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Satisfactory or better all areas: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Marginal or better in all areas: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Not proficient in at least one area: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives
NEW KNOWLEDGE (SO7): Acquire and apply new knowledge as needed, using appropriate learning strategies.	Detailed review of existing work is completed. Enthusiastically engaged in learning new material, beyond the scope of the project.	A review of existing work is completed. Fully engaged in learning new material across required aspects of the project.	An incomplete review of existing work is completed. Struggled and/or unmotivated to pursue new material in major areas of the project.	A review of existing work was not completed. Very limited pursuit of new material across the project and had detrimental impacts.	Failed in multiple regards to have the initiative and/or commitment to acquiring and applying new knowledge.

While many of the scores within the rubric are the same for each student within the design team, there may be differences. For example, in the communication and teamwork categories, a student is scored based on his/her performance in those areas. A completed rubric for a team's written design report is shown below in Figure 4 as an example.


MADN-CME
SUBJECT: Administrative Instructions for CE493

b. The following rubric will be used to assess the common graded events:

Civil Engineering Student Outcome	A+ / A 94-100	A- / B+ / B 93-84	B- / B / C+ 83-77	C / C- 77-70	D / F 69-0
DESIGN. Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	Problem clearly identified with no assistance. Exceptional technical and creative solution. Consistently engaged and exceeded project criteria. Professional standards exceeded in all areas.	Problem clearly identified with some assistance. Strong technical and/or creative solution. Consistently engaged project criteria. Professional standards exceeded in some areas.	Problem identified with some assistance. Average technical solution with minimal creativity. Met most of the project criteria. Professional standards met in all areas.	Problem identified with significant assistance. Marginal technical solution with very little creativity. Struggled to meet the project criteria. Professional standards no met in some areas.	Failed to identify problem effectively. Sub-standard technical solution with no creativity. Failed to meet the project criteria. Professional standards not met in most areas.
BREADTH. Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.	Appropriately identified all breadth areas of design. Produced solutions that met all identified breadth areas. Solutions exhibited strong technical understanding.	Appropriately identified all breadth areas of design. Produced solutions that met most breadth areas. Solutions exhibited good technical understanding.	Appropriately identified most breadth areas. Produced solutions that met most breadth areas. Solutions exhibited average technical understanding.	Failed to identify some breadth areas of design. Solutions did not meet all breadth areas. Solutions exhibited limited technical understanding.	Failed to identify breadth areas of design. Failed to produce solutions for any breadth areas. Solutions exhibited no technical understanding.
COMMUNICATION – WRITTEN. Communicate effectively with a range of audiences. (based on West Point Writing Program)	Exemplary in all areas: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Exemplary at least two areas and satisfactory in all others: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Satisfactory or better all areas: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Marginal or better in all areas: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation	Not proficient in at least one area: 1. Substance 2. Organization 3. Style and Presentation 4. Mechanics & Correctness 5. Documentation
COMMUNICATION – ORAL. Communicate effectively with a range of audiences.	Well-rehearsed and professional presentation of technically exceptional content.	Above average professional presentation of technically strong content.	Average professional presentation of average technical content.	Below average presentation of average technical content.	Below average presentation of below average technical content.
TEAMWORK. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	Exemplary in all areas: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Exemplary in two areas and satisfactory in all others: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Satisfactory or better all areas: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Marginal or better in all areas: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Not proficient in at least one area: 1. Providing leadership 2. Creating collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives
NEW KNOWLEDGE. Acquire and apply new knowledge as needed, using appropriate learning strategies.	Detailed review of existing work is completed. Enthusiastically engaged in learning new material, beyond the scope of the project. Exceeded expectations in area.	A review of existing work is completed. Fully engaged in learning new material across required aspects of the project. Met expectations in this area.	An incomplete review of existing work is completed. Struggled and/or unmotivated to pursue new material in major areas of the project. Marginally met expectations.	A review of existing work was not completed. Very limited pursuit of new material across the project and had detrimental impacts. Failed to meet expectations.	Failed in multiple regards to have the initiative and/or commitment to acquiring and applying new knowledge.

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Figure 4: Example rubric for written design report

The assessments for all the capstone projects, using the rubric above, along with other direct and indirect indicators, are consolidated into the course assessment that is used to assess the course-level objectives. Since the bridge design-build projects are only one of several types of capstone experiences and the focus of this paper is simply on that project, the overall course assessment is not shown.

The decision to incorporate a design-build type project was based on factors discussed during the CE493/494 course assessment, including student exit surveys that indicated a desire for more hands-on experiences and a valid need within the local community. The author does not have definitive comparative data to clearly show how this project specifically improves student learning, or how it compares to a control group or historical data before this type of project was incorporated into the suite of capstone projects. However, the design-build project assessments have been very strong in all categories of the rubric during the past three years. In two of the past three years, the bridge design-build team was recognized ahead of 7-9 other teams as the best capstone project team by an external set of judges who evaluated their project presentation at the end of the semester. More than 50% of the students identified a design build project as their top choice when selecting their capstone project which is indicative of their inspiration and motivation for these types of projects. The stakeholders have been extremely pleased with the projects and have expressed a desire to continue the relationship and potentially expand to other state parks in the area. Lastly, several students have provided unsolicited feedback pertaining to their capstone experience, stating that doing things like this project are exactly the reason they chose civil engineering as their major.

Conclusion

While this type of project is certainly contingent on having a partnership with organizations that have needs and a funding source, the author is relatively confident the program will continue with these types of projects. So far, we have only focused on one trail in one of three state parks in the area. Both the state park and the organization that provides the project funds, have expressed a desire to continue the relationship for as long as we have students who are interested. Additionally, other local communities have reached out and asked our program to partner with them to do similar type design-build projects. The author feels this type of project can be adapted by other institutions; however, it is important to ensure the project is scoped such that it can be completed within an academic year, and that funding and permitting responsibilities are clearly established.

The design build capstone project experience at the United States Military Academy has been established to address student feedback and interests, legitimate real-world needs of the neighboring community, and to meet the ABET program criteria for undergraduate civil engineering programs. The author feels these design build projects provide students with an authentic and exciting design challenge that motivates students and promotes their learning and development as engineers; thus, spanning the gap between the classroom and professional practice.

Acknowledgement

The author would like to acknowledge the members of the NY Taconic Region and Fahnestock State Park, along with members of the Open Space Institute, for their partnership in providing the opportunities for these projects to take place.

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