Implementing a Student Design-Build Project in One Semester

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Abstract

This paper describes a one-semester design-build capstone project in which three senior civil engineering (CE) students designed, completed an environmental assessment, gained approval, and built a 28-foot timber pedestrian bridge. The course was taken as part of the ABET-accredited CE program at the U.S. Military Academy. The team addressed public accessibility to the only maintenance break area through construction of a timber bridge to replace the deteriorated foot bridge that had carried workers across an intermittent stream. With the loss of the previous foot bridge, the break/smoking area was accessed by walking along the busy motor pool entrance road (safety) to the vehicle bridge crossing the stream (time). The narrow vehicular bridge, which is located on a sharp bend in the road, is over 50 yards from the maintenance facility while the break area is located a mere 10 yards away on the other side of the stream.

Key educational benefits gained by the students who completed it include grappling with real-world constraints, solving substantial engineering problems, dealing with issues of safety and constructability, coping with construction management difficulties such as placing the concrete with a 1 cubic yard mixer and bags of concrete, miscommunication, delayed construction approval, and most importantly, bringing a project from concept through completion. Student assessment data demonstrates that such projects contribute much, not only to students' learning, but to student's motivation and self-awareness as well. Any design-build project forces the students to develop resourcefulness, perseverance, adaptability, and creativity. One student's comment: "I learned more in this course than any other I have taken in the program."

I. Introduction

One of the many pillars of any educational endeavor is to gain understanding from doing—to experience firsthand the methods and principles learned in countless hours of classroom instruction and individual study. Such opportunities often present themselves in unexpected or seemingly insignificant places. Masked behind West Point's pristine landscape is an organization that goes largely unnoticed due to its behind-the-scenes role in USMA's daily operations. However, without this facility, some of the Academy's basic functions would not be possible. The Transportation Motor Pool (TMP) provides the mechanical and technical support to hundreds of vehicles not only used for cadet training, but also for the daily upkeep of West Point's cherished grounds, historic structures, and winding roads.

Meandering beside the TMP maintenance garage, a small intermittent stream restricts access to the employee break area on the far shore. Because of the high safety risk and stress involved in operating tools and large machinery in the maintenance area, the necessity of providing breaks to

employees proves to be particularly critical. While an old decrepit footbridge once allowed workers to travel to the break area, its deteriorating condition forced its removal several years ago. Since OSHA safety regulations forbid employees from breaking within the maintenance area, they are faced with an often dangerous and lengthy trip along an access road and across a narrow vehicular bridge to the other side. Due to the inherent hazard and inconvenience that this poses, the motor pool staff contacted West Point's Director of Housing and Public Works (DHPW) and the Department of Civil and Mechanical Engineering (DCME) to develop a solution. Ultimately, three senior civil engineering students elected to take on this challenge as their culminating design project.

Project coordination began with DHPW to acquire resources and clearance to complete the project. Students sent project proposals thru the post self-help center (replacing a previously existing bridge) and the design offices of DHPW (design approval, digging permits and environmental assessment) to gain key approval to complete the work prior to their graduation. Once the project was approved, the materials were acquired through the DHPW lumber yard and construction was completed during the last week of the semester. Additionally, the students submitted a detailed project report, provided a formal briefing, conducted a formal ribbon cutting ceremony, and provided formal assessment of the project.

II. Bridging the Gap

In order to incorporate the entire design/build spectrum of a capstone project into the team's final semester at the Academy, faculty advisors present the various project options and assemble corresponding teams early each fall. Planning and preparation often occur long before students return from their winter leave to ensure that adequate time and resources are available to successfully complete the project before graduation in May. There are essentially three basic genres of senior capstone projects: research-based, competition-based, and service-based. The Motor Pool Bridge project fell into the most sought after form of project in the department—the service-based project. The three seniors selected for this project expressed a strong desire to develop the need of the motor pool staff into a well-articulated plan, and finally construct a physical product allowing employees convenient access to their break area across the stream. The project began by meeting with motor pool supervisors to incorporate the vision of the client into a well-defined project scope that would allow for the development of an actual design. Additionally, coordination was required with DHPW to request resources and initial project approval. There the team discovered that although they did not need to gain approval from the planning board since the bridge construction was classified as a "self-help" project to replace a pre-existing structure, they were obligated to obtain authorization for construction after a review under the National Environmental Policy Act. A self-help project refers to a project funded and supported by DHPW where the labor is provided by the tenant of the property being improved or constructed upon. After project approval, the students acquired the necessary materials to complete their design for a 28-foot wooden truss bridge capable of supporting foot traffic from the motor pool maintenance garage to the break area across the stream.

In order to bring this project from an idea on paper to a structure in the ground, the students had to both employ practices and utilize resources that are valuable to engineers. Specifically, they:

- conducted a reconnaissance,

- surveyed the work area,
- developed a three-dimensional map of the area of interest using a computer based terrain analysis program,
- coordinated with outside agencies to gain support for the project,
- worked with the DHPW engineer for record to get his stamp of approval on their design,
- lobbied DHPW to provide skilled technical support and funding to support the work,
- constructed a combined 28-foot of timber bridges capable of supporting over 6,000 pounds of traffic,
- assessed the finished product and the steps they took to get there, and,
- performed a dedication ceremony prior to their graduation.

The team's real effort began near the end of the fall semester when the students made a few trips to the motor pool to conduct a reconnaissance of the site and to start visualizing how to address the presented problem. They quickly decided to each develop an alternative solution to the problem and then decide after further research and reflection which alternative best met the client's needs and would be the most cost and fabrication efficient. Prior to winter leave they conducted a site survey using a Total Station Surveying device and a digital camera. After surveying approximately 200 points, they were able to computer-generate a topographic map of the proposed construction site. They used this large scale map in addition to several photographs clearly depicting the contour of the stream to develop a plan and compare their alternatives. From this analysis, it was clear that the previous location of the bridge near a bend in the stream would lend to design difficulties and ultimately limit the durability of the bridge because of the significant amount of erosion observed in this area. Consequently, a site (Figure 1) approximately 50-feet downstream and directly across from the break area was tentatively selected because of the relative straightness of the stream flow path, the width of the gap to be

Figure 1. Intermittent Stream

spanned, and the closer proximity to motor pool facilities. Additionally, the map and photographs allowed the team to accurately determine the actual length and layout of the bridge and present their concept for the design during the winter months when West Point was completely covered in snow.

With a concept of how the bridge footprint would be situated on the project site in hand, the team set out to develop multiple courses of action to meet the objective of spanning the stream. Several designs were considered based on their relative constructability, ease of design, availability of materials, and consistency with local building architecture. Ideas ranged from using laminated dimensional lumber for beams, to constructing a reinforced concrete deck with a steel beam substructure, to locating telephone poles (beams) meeting the length requirements for the bridge. However, the team eventually selected a timber truss design due to the widespread availability of pressure treated lumber in the DHPW lumber yard and the aesthetic appearance that a wooden bridge provides in this natural setting. The students developed tentative drawings using AutoCAD 2002 (Figure 2) and modeled the performance of their design under various loading conditions in Visual Analysis which accounted for dead, snow, and pedestrian loads based on its anticipated use. These tools allowed for the preliminary sizing of members, the development of a bill of materials, and the design of the bridge's foundation system. Additionally, extensive hand calculations showed that the bridge could adequately handle the various forces applied to its members and connecting elements. Though timber design is not a course presently available at USMA, the students taught themselves (this is an independent study course) the rudiments of timber design using fundamental engineering principals and timber design manuals and textbooks (1,2). The abutment design also required an extension of the basic knowledge developed in their concrete design class.

After developing a functional design and corresponding bill of materials, in-depth coordination with DHPW began in late March—the first step for any construction on West Point. The DHPW structural engineer reviewed and approved the student's design and plans as if they were a junior engineer working for him. While the DHPW Self Help Center proved to be extremely eager and willing to help with the project, the team quickly discovered that a large degree of coordination

Figure 2. Bridge Design in AutoCAD

across many shops was needed to occur to bring the bridge to a successful completion and adhere to their construction schedule—from acquiring and transporting the materials, to addressing several environmental concerns, to foundation digging on the project site (Figure 3). DHPW immediately began requisitioning lumber, hardware, and concrete, while the team gained environmental approval to dig and construct a bridge on the site. The environmental review required footer placement above the mean high water table, mandated no cutting of materials

Figure 3. Foundation work

over the stream, and specified the use of bailed hay to prevent soil erosion during excavation. Shortly after receiving the digging permit in mid-April, stakes were placed to locate the position of each footer, and a DHPW ground maintenance crew dug the six-foot holes necessary for each footer using a backhoe. SonoTubes measuring two-feet in diameter served as formwork for the eventual concrete placement of the foundation.

Almost all construction occurred after the completion of normal daily classroom activities, so it became difficult to fully utilize the help of various DHPW departments since normal working hours seldom overlapped with the time students could be at the project site. Consequently, coordination and clear communication of the design became a vital aspect of the bridge construction. Concrete placement proved to be one such obstacle that the team faced. Though the students anticipated using Quikcrete, a small mixer, and a wheelbarrow for the entire job, placing almost three cubic yards of concrete by hand is no small task. Realizing this, a DHPW roads and grounds crew placed the remainder of a ready-mix batch into two of the SonoTubes. However, team members were not present while this occurred to embed two 4x4 boards into the concrete to serve as a bearing surface for the bridge, so the abutments began to cure without these critical members. While a slight design modification eventually worked around this problem, it could have been eliminated altogether with better communication of the design to all involved parties or simply with the ability to be on the job site.

By late-April construction showed rapid progress as students spent late nights and weekends in the depths of the Civil Engineering Department's project facility prefabricating the wooden trusses and other components of the bridge (Figure 4). This process not only involved cutting each section of the truss to size, but also securing each connection with custom-made steel gusset plates. The massive 28-foot trusses were then lifted by a telescoping forklift onto a flatbed semi that transported them to the motor pool. At the bridge site, a DHPW crane awaited the arrival of the trusses and lifted them over the stream to their final position on the abutments where the team proceeded to install the bridge deck and assemble the lateral support system. During the construction phase, the students had to modify parts of the design for the sake of constructability and performance—very similar to any other construction project. For example, they added three 2x6 sections to the bottom of each lateral support to reduce the tendency of the trusses to bow

outward once the lateral construction supports were removed. The change came as an experienced-based recommendation from the departmental carpenter and several of the instructors in an effort to maintain the effectiveness of each truss by forcing them to act in the vertical plane.

Figure 4. Truss Construction

Other construction tasks included:

- marking and preparing the site,
- placing formwork,
- mixing the concrete in an electric-powered mixer manually moved to the far shore of the bridge site (the side not placed by the ready-mix truck),
- cutting, drilling, and priming 50 steel gusset plates,
- bolting together each truss section,
- hauling all materials and equipment to the construction site,
- securing the deck and lateral support to the trusses,
- building a wooden staircase and railing on the far side of the bridge,
- always maintaining the site to return to pre-existing conditions, and,
- installing a sign prepared by the DHPW Sign Shop.

In the end, the final product exceeded the student's initial expectations in terms of both its quality and its appearance (Figure 5). They are very proud of the work they did and are confident that the bridge will serve both as a means of preserving a path to the motor pool break area, and as a tribute to the quality engineering West Point was founded on. The site was dedicated one week after completion of the construction during graduation activities. It was perfect timing to include family to be part of the festivities since they were present for graduation.

Figure 5. Bridge Near Completion

III. Key Educational Benefits

In large part, the greatest lesson learned was timely completion of the bridge now carrying motor pool employees across the stream to their break area. Given the effort put into making sure the bridges were designed to withstand the expected extreme loading (i.e., large factor of safety), the students are confident that the fruit of their labor will last for many years to come and that they are prepared to complete even larger projects in the future. Bottom line: they have a better understanding of the constraints related with initiating any project, the difficulty of building what is designed, and to expect the unexpected during construction.

In reference to the design work the students completed for the timber spans and the concrete abutments, they discovered several interesting learning points. First, the most obvious lesson learned was how to design timber structures which is not offered as a course at West Point. They discovered through self-study that timber design is in many ways similar to steel or concrete design though there are significant differences in material properties. As for concrete design, they learned to build on previous course work to learn how to design abutments. More important are the lessons that cannot be taught in the classroom and must be learned on site: how to actually construct timber and reinforced concrete design concepts. Unique designs that cannot be constructed easily are useless and simple designs are sometimes better.

In reference to the interactions with the numerous professionals working at DHPW, the students discovered that many aspects of light construction are determined more through experience and conservative estimations rather than on hard and fast engineering design. They discovered that the scope and cost of a project such as theirs was relatively small, and that it is often times easier to over-design (or overestimate) the structure in favor of being expeditious. The cost difference between an efficiently designed structure of this magnitude and an over-estimated one is fairly insignificant. They learned that this sort of project does not usually require an engineered design

and are seldom designed mathematically, but are instead designed from experience—something they do not have yet.

Possibly the most intriguing and educational aspect of this project was the coordination they conducted with DHPW and its associated departments. The coordination process exposed them to the system that engineers and contractors must go through to convert a design into a reality. They interacted with mechanical and structural engineers, supervisors, construction estimators, carpenters, environmental engineers, the motor pool supervisor (the customer of sorts), and many others. In the end, they found that each of these people may have a real interest in the project and can contribute much to the success of the project. Similarly, the interaction with each of these individuals had to be on a personal level. The students had to spend time with each person to prove that they cared about what the other was doing. People will do their job because that's what they get paid to do. They will only excel, however, when they like the people they work with and for. Additionally, as soon as this project gained final approval, it became a mission not only for the student team, but also for the professionals at DHPW. They take pride in getting the job done to standard, and it truly was refreshing to interact with so many motivated people.

On site, they learned a lot about what works in theory and what works in practice. They began to see what factors affect the constructability of a project and how to maintain a fluid construction process to facilitate sudden changes. Care must be taken, however, to maintain quality control in what can quickly become an out of control construction site. For example, the lateral support design literally changed overnight based on the recommendation of several instructors and a carpenter. Within 24 hours of its conception, the students were on site bringing the trusses back to their true alignment with an engine block puller borrowed from the motor pool staff and attaching reinforcement to the substructure of the bridge. The speed of changes is similar to requirements on any job site when structural members do not show up or are the wrong length. The engineer of record is still responsible and must analyze and approve all changes. Constant communication is critical. One of the students had to become the construction foreman. In the absence of a construction foreman, the momentum to just build and get it done can lead a construction crew into making bad decisions. For example in this project, the concrete on the near side of the bridge was placed before the formwork was completely level across the span of the bridge. The students did not immediately correct the problem since they were absent from the site when the concrete was placed. Consequently, they later built up the near side of the bridge by anchoring stacked 2x6's into the concrete footer to bring it back to level and to provide proper support and connection for the bridge.

IV. Assessment

Student web-based assessments at the end of the experience were extremely supportive of design-build projects. Students responded to web-based statements using a scale of 1-5 (strongly disagree – strongly agree). The responses (Table 1) for the project were compared to the averages for USMA, the department, and the course depending on what level the statements were generated at.

This design-build project was one of 20 separate capstone projects during the spring. Initially, these type of projects were only for the top 2-3 students within our program. However, the

inclusion of competition-based projects (e.g., steel bridge and the concrete canoe) required an increase in students participating and inclusion of students (e.g., welding skills, desire to be part of the competition, etc.) sometimes in the lower performance tiers within the civil engineering program. However, the results clearly show that the experience is extremely valuable for all members of the program and the 20 projects represent the minimum required number of projects for our program to ensure each student has the option of participating in a project similar to the one described in this paper (3).

As can be seen in the table, some of the responses are directed toward the instructor. However, the instructor for most of the projects met with the students only once a week to discuss what they accomplished since the last meeting, what they plan to accomplish by the next meeting, and to provide guidance and ask questions to help direct the teams effort. It is obvious the students thought the conduct of the weekly meetings constituted a plan similar to other instructors during daily classroom sessions. Based on the results, the students felt that the project motivated them to learn on their own, stimulated and increased (creative) thinking, and they feel comfortable solving complex, real world problems.

Table 1: Web-Based Responses		
USMA Wide Statement	Project Average	USMA Average
Instructor encouraged student's responsibility for learning	4.62	4.45
Instructor cared about my learning in this course	4.57	4.41
Motivation to learn increased	4.2	3.96
The instructor stimulated my thinking	4.43	4.22
Critical thinking ability increased	4.5	4.08
Department Wide Statement	Project Average	Dept Average
Instructor had a plan for every lesson	4	4.75
Instructor helped me understand the importance and practical significance of this course	4.8	4.4
Course Wide Statement	Project Average	Course Average
I can apply the engineering thought process to solve a complex, real world problem	4.4	4.06
I can develop a creative solution	4.32	3.95
I can acquire information and learn new concepts on my own	4.26	3.95

Some of the important things learned:

- Pushing a project through the system.
- Time management – design is easier than construction (at this level).
- Need for creative thinking when resources are low.
- Nothing goes according to plan.

Some strengths of the course:

- Responsible for own learning.
- Forces time management.
- Use most of developed CE skills.
- Hands-on skills are invaluable.
- REAL project.
- Wraps up entire CE experience.

A few of the free-form comments were:

- This project was a great experience for us. I think more students should get the opportunity to actually go from design through construction.
- Someone must take the leaders role even in student group projects.
- We worked hard, but can now actually look back (with pride) at a project we took from concept to a finished product.

V. Conclusion

The true measure of success of the project is now standing across a creek just inside West Point's Washington Gate. The impact of this project on the three students who completed it will also be lasting. The benefits of grappling with real-world constraints, solving substantial engineering problems, construction on an environmentally impacted site, dealing with issues of safety and constructability, coping with construction management difficulties such as conflicting schedules between themselves and DHPW, and bringing their project from design to final product are immeasurable. The coordination and effort they put into taking this project from concept to completion in one academic semester, a feat many thought not possible, has prepared them for the future design-build projects they will undertake as engineers.

The detailed description of the bridge project highlighted the educational benefits of design-build projects for any engineering student. Student assessment data demonstrated that such projects contribute much to student's motivation and self-awareness as well. One student's comment sums it all up: "I learned more in this course than any other I have taken in the program." They are proud of the work they did and are confident that this bridge will serve both as a means of linking motor pool employees to their break area and as a tribute to the quality engineering on which West Point was founded.

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