How Do We Take Full Advantage of the Academic Benefits of Student Competitions

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Case Study - How do we Take Full Advantage of the Academic Benefits of Student Competitions

Abstract

The American Society of Civil Engineers (ASCE) organizes and hosts two popular civil engineering student competitions each year: Concrete Canoe and Steel Bridge. Many colleges and universities that compete in these competitions are voluntary clubs for students ranging from freshman to graduate students. Their primary purpose, to win. However, winning is not the only benefit of these competitions. By participating, students are exposed to an open-ended, interdisciplinary problem, which requires them to think critically about a problem and formulate innovative solutions. Moreover, it provides the students an opportunity to apply the technical knowledge gained during their academic journey such as structural analysis, project planning, design optimization, sustainability, and cost analysis to a real-world scenario. Many of these desired goals are difficult to attain in a traditional classroom setting and may not be realized till students complete their senior capstone design projects. Capstone projects are the culminating experience for undergraduate civil engineering students. Performance on these projects may serve as an individual assessment tool to evaluate student learning outcomes in accordance with the Accreditation Board for Engineering and Technology (ABET). The ABET student outcomes include a student's ability to solve problems, apply new knowledge, design, communicate both written and orally, conduct experiments, function effectively as a member of a team, and recognize ethical and professional responsibilities. One of the main challenges for civil engineering programs is individually assessing each student's performance for each outcome. Typically, the students' performance in their senior capstone project is a primary metric. This project details the multiyear evolution of offering the ASCE Concrete Canoe and ASCE/American Institute of Steel Construction (AISC) Steel Bridge Competitions as senior capstone experience to individually assess student outcomes. This paper aims to summarize the advantages of using the student competitions as senior capstone design projects as previous research has shown. It specifically outlines the organization and assignments used to assess both individual and group performance. It will detail how instructors can use various aspects of the student competitions to assess each student outcome on an individual basis.

Introduction

All undergraduate engineering programs are required to have a culminating engineering design project. The Accreditation Board for Engineering and Technology (ABET) defines a culminating design project as, "1) incorporating appropriate engineering standards and multiple constraints and 2) is based on the knowledge and skills acquired in earlier coursework" [1]. The optimal design of a capstone should inspire students and allow for creative design opportunities, but students should also be given the chance to fail and learn from their mistakes [2]. Typical projects do not have an obvious solution and thus lead to failure during the first attempt. Students must experiment and prototype providing them with an iterative design experience. When faculty assess student performance in their culminating design process, they are evaluating the student's ability to solve, design, communicate, experiment, apply new knowledge, and work effectively on a team all within the profession and ethical guidelines applicable to engineering. These seven student outcomes are outlined by ABET. ABET requires faculty "develop and implement processes for the evaluation, assessment, and continuing improvement of the program" [1]

There are various methods used by universities to complete a culminating design project. One of the methods is a paper based designed. Design-build projects are another option and are often externally sponsored either by industry companies, research laboratories, or societies [3]. A national survey conducted in 2005 revealed that engineering programs are emphasizing the importance of teamwork in capstone projects, and therefore are shifting away from projects that are completed by an individual student towards team-based projects [3]. This study also revealed that typically a capstone team is comprised of four to six team members completing the project as a one or two semester capstone course [3]. One challenge with a design-build project is that it can be difficult to develop a project that a small team can complete in a short time frame of one year or less [4]. Additionally, it is important that the project selected is viewed as worthwhile by both the students and the faculty for it to be successful at achieving the student outcomes [2].

Partnering with an industry sponsor is one potential solution to this challenge. An industry sponsor can help develop the capstone project's goals and often can appropriately scope one aspect of a larger project to serve as a capstone project. An industry sponsored project is not only a viable solution but also enables the achievement of the ABET student outcomes. An open-ended industry sponsored project forces students to solve complex engineering problems and develop creative solutions. For industry sponsored projects, students must assess their solutions through experimentation and often require significant effort to learn new knowledge such as software or analysis methods [5]. Since most projects occur over a full semester or a full academic year, it is often necessary to demonstrate strong project management skills [3], [5]. The most difficult outcomes to assess are communication and teamwork, but the student teams recognized and valued the need to work together and communicate their technical knowledge effectively [5].

While there is great benefit to working with an industry sponsor for capstone projects, it is not always feasible to find an industry partner to work with students, especially undergraduate students. Within the last 20 years, professional societies have developed student competitions designed similar to culminating capstone projects. These competitions are designed for undergraduate students to apply the engineering skills they have learned during their curriculum to solve a complex, real-world problem. Miller et al demonstrated that student competition projects are comparable to industry-based projects [6]. Previous research has documented the value of incorporating these engineering design competitions into undergraduate curriculum [6], [7], [8]. The competition aspect of the projects positively impacted the technical and leadership abilities of students, increased motivation, and further stimulated learning[9], [10]. The engineering programs benefit through effective resource management and easier recruitment of team members to participate on competition teams [11].

The measure of success in using student competitions to meet course learning outcomes is aligning course assignments and outcomes directly with the student competition [12]. A student's grade and measure of success in the course cannot be tied directly to the competition performance. Rather the student's grades should be tied to the student's demonstrated knowledge and ability to meet the learning outcomes of the course [13]. In the instance of a capstone project, the course outcomes are nested within the ABET student outcomes.

There are many student competitions including the American Society of Civil Engineers (ASCE) Concrete Canoe Competition, the American Institute of Steel Construction (AISC) Student Steel Bridge Competition (SSBC), the National Aeronautics and Space Administration (NASA) Lunabotics Mining Competition, Prestressed Concrete Institute (PCI) Big Beam Competition, and the Society of Automotive Engineers (SAE) Baja Competition just to name a few[6], [13], [14], [15]. In civil engineering, the two most well-known and long-standing student competitions are the ASCE Concrete Canoe Competition and AISC SSBC. This paper will focus on outlining effective methods to implement these two competitions as a culminating capstone design-build project to meet each ABET student outcome.

Both the SSBC and Concrete Canoe competitions emerged as engineering faculty sought opportunities for their students to get hands-on experience in engineering design that paralleled aspects of the engineering profession. Steel Bridge competition is jointly sponsored by AISC and ASCE and began in 1987. It has been a national competition since 1992. Today nearly 200 schools compete in the competition. The mission of the SSBC is to "challenge students to extend their classroom knowledge to practical and hands-on steel-design project that grow their interpersonal and professional skills, encourage innovation, and foster impactful relationships between students and industry professionals" [16]. Concrete Canoe competitions began in the early 1970s [7]. The first national competition was held in 1988 at Michigan State University and was coined, "Americas Cup of Civil Engineering". The mission of Concrete Canoe is to test the student team's skills with concrete mix design and project management while developing professionally through networking and competition [17]. Up to 250 schools compete each year at the regional level in an effort to earn a slot at the national competition.

Many of the requirements of the Concrete Canoe and SSBC naturally align with the ABET student outcomes. The Concrete Canoe competition requires each team to write a technical proposal, give an oral technical presentation, provide a final product prototype, and conduct a prototype demonstration [17]. The technical proposal and oral technical presentation directly correlate to the communicate ABET student outcome. The final product prototype requires the students to solve, design, experiment, and apply new knowledge. The SSBC includes competition categories for aesthetics including a poster describing design, construction speed, lightness, stiffness, construction economy, structural efficiency, overall performance, cost estimation, and an optional video category [16]. The aesthetics and video category provide an opportunity for technical communication. Success in the other categories requires design, experimentation, and application of new knowledge.

There is a fair amount of previous research that discusses competition-based learning. Barry et al conducted a survey to assess the effectiveness of intercollegiate competitions at achieving the 24 outcomes of the ASCE Body of Knowledge (BOK2) [13]. Many of these studies even address ABET criterion three, student outcomes, through student competitions. Miller et al outlined a procedure for assessing the achievement of ABET student outcomes while working on a team for NASA's Lunabotics Mining Competition, through interviews conducted by the ABET advisory board [6]. Koehn provides a map showing the link between the ABET student outcomes and the specific requirements of the SSBC competition. While the connections are clear the map demonstrates how the team achieves the ABET outcomes, but now how each individual student demonstrates achievement of the student outcomes [8]. A study conducted at the University of Louisiana assessed achievement of the ABET student outcomes as part of an engineering design-build competition through a survey completed by the students that participated in a competition project [18]. These achievement assessments of the ABET student outcomes are focused on the team achieving the outcome or based on student perceptions.

On a competition-based project, the project manager uses the work breakdown structure (WBS) to manage tasks [7]. This paper aimed to demonstrate how the WBS can be used to demonstrate achievement of ABET student outcomes individually for each team member.

This case study's objective was to provide a framework to individually assess the achievement of the ABET student outcomes for each member of a competition team. This research study investigated the implementation of two ASCE Student Design Competitions: the AISC Student Steel Bridge Competition and the ASCE Concrete Canoe Competition, as culminating capstone design projects. The authors assessed best practices from other programs outlined above in their success assessing individual student outcomes by improving team dynamics, including individual assignments, and incorporating creative brainstorming sessions. Over several years, a framework for assessing ABET Student Outcomes in civil engineering competition-based capstone projects. The research questions this study sought to answer were:

1. How can faculty members design competition-based projects to help students achieve individual ABET Student Outcomes?
2. How can faculty members assess and document individual contributions through ABET Student Outcomes?

Methodology

The United States Military Academy has been competing in Steel Bridge and Concrete Canoe for over 25 years. Initially the teams would complete the project during a single semester independent study project. However, as the competition evolved it became too difficult to complete in just a few months. To resolve this, in 2012 both the Steel Bridge and Concrete Canoe competitions were offered to students as a yearlong capstone project. At the institution where this study was conducted, each graduating civil engineering class has ranged from 30-50 students. For their culminating capstone project, they are assigned to a project in teams of 3-7 students. Selection of their capstone project is dependent on several factors including their interests, expertise (previous electives/course taken), attributes, and availability. Along with competition-based projects such as Steel Bridge and Concrete Canoe, students may choose from sponsored research design projects or community service design-build projects.

The capstone course consists of a project completed over two semesters, giving the students an opportunity to apply and integrate their civil engineering knowledge from multiple sub-disciplines in an open-ended project. Paramount to the capstone experience is the application of the engineering design process. By implementing the Steel Bridge and Concrete Canoe competitions as a project in the capstone course, it ensures that the projects have dedicated leaders, advisors, time, and resources to facilitate competing at a high level. The capstone program includes both group and individual graded requirements broken down into course directed group deliverables (25%), individual ABET student outcome assessments (40%), and project specific requirements (35%). The project specific requirements are agreed upon by the students and the advisors. The ABET student outcomes assessed in the capstone course are solve, design, communicate, experiment, teamwork, and application of new knowledge. The project advisors are responsible for the individual assessment of the ABET student outcomes.

Large design projects, such as competition projects, create a challenge in assessing each student individually for achievement of the ABET student outcomes. It is important that the teams are sized appropriately to have enough students to complete the build portion of the project, but not too many to hinder each student from completing an individual design to be evaluated on. Typically, each team member is assigned a role with specified duties and responsibilities associated with an individual design component. The role assigned to each team member should be similar in scope and provide an opportunity for an individual assessment of each of the ABET student outcomes. Clearly defining the duties and responsibilities at the start of the project ensures that each student is contributing to all areas.

Individual ABET student outcomes can be assessed both qualitatively and quantitatively. In previous research, surveys and interviews were used to conduct a qualitative assessment of the ABET student outcomes [6], [18]. The capstone course at the United States Military Academy took a different approach, developing an assessment form modeled off an employee appraisal form [19]. The assessment form (Appendix A) provided an opportunity for student reflection and discussion between the student and the advisor to ensure that the students perceived effort and achievements in each category matched the advisor's assessment. Also, individual deliverables or graded assignments were assigned to each student to provide a quantitative assessment of the ABET student outcomes. A more in-depth description of the assignment of roles and responsibilities and the qualitative and quantitative assessment of ABET student outcomes for the Student Steel Bridge Team and the Concrete Canoe Team are provided below.

Steel Bridge

The AISC SSBC inherently lends itself to achieving the ABET Student Outcomes and directives for a culminating design experience. The challenge with using the SSBC as the culminating engineering design experience for students is that it is a team experience. As discussed in the introduction, team projects leave room for social loafing and overall inadequate performance individually regardless of team performance.

Over the past 3 years, the Steel Bridge Team at the United States Military Academy efforts to streamline the project. These efforts included providing students with a dedicated workspace to fabricate the bridge in-house, incorporating similar design aspects into the basic Structural Analysis course [20]. forming diverse and interdisciplinary teams [21], [22], and recruiting underclass students to participate in the team during their freshman, sophomore, and junior year to provide continuity to the team. The performance of the Steel Bridge team has significantly improved; qualifying for the National Competition for the first time in school history, by means of a wild card spot, in 2023.

The team was generally comprised of five to six senior engineering students consisting primarily of civil engineering students but including mechanical and systems engineering students to provide a diverse prospective. Each team member was responsible for multiple project roles throughout the project. The project structure followed the engineering design process from problem definition, conceptual design and analysis, decision making, preliminary designs, implementation, and solution. From there, it was divided into two distinct stages: design and construction. However, the iterative design process was emphasized during both stages, as students completed requests for information and proposal requests for design changes when they ran into issues.

The project's design stage was conducted throughout the fall semester and the construction stage in spring. Design consisted of 2D and 3D structural models, hand calculations, design iteration, and development of shop drawings. Construction consisted of fabrication, timed construction, load testing and repairs or modifications. The project's distinct stages, each with many roles, posed a challenge when delineating responsibility to each team member. To navigate this challenge, each senior was assigned lead of at least one of the project roles. The roles ranged from project manager, structural engineer, connection designer, fabrication lead, and drafter. Subsequently, each member was assigned secondary roles as an alternative. This served two purposes: first, the burden of work was split between two people to promote flexibility, efficiency, and maintaining accountability in support of the project timeline and, second, work was consistently reviewed by another peer, to promote professional engineering practices.

To ensure progress was maintained and tracked, the project manager was consistent throughout. Additional team members were recruited from underclassmen interested in completing the project for independent study credit. Independent study projects ranged from 1, 2, or 3 credit courses. These additional team members were directed to work on a specific aspect of the project of interest to them, or areas where the team needed additional support, such as fabrication or connection design. Another challenge was achieving consistent individual growth as an engineering student on the Steel Bridge team.

When establishing the team, the team roles, and the team goals, the team learned and reflected on each of their strengths and personal goals for the project. The project manager was the first position appointed. The project managers primary goals included maintaining responsibilities and accountability of all members on the team, routinely checking, and updating the project schedule, and acting as the primary liaison for communication with faculty advisors and other faculty support such as lab technicians and acquisitions. The project manager established the structure, focus and efficiency of team meetings and work sessions. Faculty advisors also played a critical role in supporting the team and steering the team in the right direction while still allowing the team leeway to operate independently. Deliberate faculty involvement with the team and mentoring individuals was required to maximize the Steel Bridge team's achievement.

The remaining team roles were finalized later in the project. Each member of the team was required to contribute to problem identification and conceptual designs at the beginning of the design stage. This was found to be essential for individual development, creative idea generation, and collective success. This process prevented specialization without comprehension of the full project scope. It also provided diversity of thought and out-of-the-box thinking. These brainstorming activities and conceptual design presentations provided technical oral and written communication opportunities early in the project and improved variety and quality of conceptual designs.

As the semester typically begins in August and the SSBC rules are not released till September, the first individual assignment for the project was a presentation on bridge inspirations. Each team member was tasked to research three real-world bridges: an aesthetically captivating bridge, an accelerated construction bridge, and a movable bridge. The purpose of this exercise was to stimulate creativity, build team comradery, and share knowledge. The second assignment was a presentation to the group regarding the SSBC rules. Each team member was assigned two sections of the rule packet. They briefed the major goals, constraints, and any ambiguities within their sections to the rest of the team. This resulted in individual familiarization with the competition rules, which was essential as most team members had never participated in the competition.

The team then participated in a mini steel bridge design-build competition. The rules of the mini bridge competition paralleled the actual competition just on a smaller scale, in terms of both time and size. The teams designed their bridge, created a cut plan, and then fabricated. The mini bridge activity exposed all team members to the nuances of designing, drawing, cutting, welding, and competing—all essential capabilities to perform well in the SSBC. The team members demonstrated a lack of fabrication knowledge during the design phase, coming up with designs which weren't feasible to construct with the team's existing tools and resources. This led to a learning experience which translated to better design assessments during the design stage for the actual competition. Most importantly, the mini bridge competition generated intellectual excitement for the project.

At this point, the team created a project contract with expectations, timeline, and team goals, wrote a problem statement, determined team roles, and established a team name. The next part of the design process was producing conceptual designs. Each team member completed at least three conceptual designs using the structural analysis software Visual Analysis [23]. To simplify the design process, the students were required to only produce 2D conceptual designs for simple bridge structures. The bridge types were limited to four categories: girder, under truss, over truss, or through truss. After generating the conceptual designs, team members were assigned another team member's design to optimize. This was to promote creativity and allow peer review of the design within the rules and regulations. The designs were optimized based on the structural cost equation from the SSBC rules, which depended on the weight and deflection of the bridge. Each team member had to present their design for evaluation and discussion.

A struggle for some students was that there was no right answer or explicit formula for the best design. However, this is the nature of the competition and typical for complex real-world engineering design problems. The project made team members comfortable being uncomfortable. The team collectively assessed evaluation criterion and success beyond the equations provided in the rules, such as fabrication feasibility and perceived timed construction. The team used the results from national qualifying teams from previous years to establish estimations for timed construction.

Once the team narrowed the focus of the conceptual designs, the team members began their specialized design stage tasks. The specialized tasks served as an opportunity for each team member to apply new knowledge.

The structural engineer was responsible for modeling and conducting analysis on the designs using Visual Analysis. The structural engineer further optimized selected conceptual designs and established a decision matrix for consistent evaluation through the optimization process. The criteria for the decision matrix included maximum deflection and estimated weight. Estimated construction speed was omitted from the final optimization phase as changes to the structural design would have a negligible effect on construction speed. Approximately 100 variations of the final design were evaluated with different cross sections, number of members, and placement and orientation of members. It was important that the structural engineer communicated with the fabrication lead throughout the process to identify available cross-sections and place a purchase request for material.

The fabrication lead's goal was success in the second semester, during the bridge fabrication process. Which means their sole focus first semester was preparing an effective fabrication sequencing plan. The responsibilities included evaluating and communicating the constructability of each conceptual design, identifying the material and available cross sections for the bridge, sourcing materials and tools, setting up the workspace and leading fabrication education. The fabrication lead was required to design and construct a jig to aid in efficient construction practices during the fabrication stage. This was especially important as team members were not expected to have fabrication experience before joining the project. It was crucial for the fabrication lead to overcome the lack of experience by educating the team members on efficient and safe fabrication practices.

The drafter was responsible for using computer aided design software to model the bridge in two and three dimensions. This helped visually communicate the design to external reviewers and assess potential challenges with fabrication or construction. The drafter was also responsible for creating accurate shop drawings, which would be used during the fabrication process for quality control and quality assurance checks.

The connection designer was responsible for the designing, analyzing, and testing bolted connections. One of the primary indicators of a successful SSBC team was the quality of their connections. The more rigid the connection the less accumulated deflection under loading and the quicker the timed construction. The connection designer was responsible for verifying all failure limit states including yielding, rupture, buckling, bolt bearing/tearout, and bolt shear according to the AISC Steel Construction Manual [24]. For complex connection designs, finite element analysis was conducted using SOLIDWORKS [25]. Prototypes for each potential connection design were fabricated and experimentally tested under tension loading in a 20-kip capacity universal testing machine.

Additional group assignments were also included to facilitate teamwork. These included daily briefs by team members, an oral interim-progress review presentation, aesthetics discussions, and a final technical report and presentation.

Concrete Canoe

Similar to the SSBC, the challenge with using the ASCE Concrete Canoe Competition as a capstone project was finding the balance between having enough team members during the construction phase and being able to assign each student a role that allowed them to be evaluated individually. A team size of five to six seniors allowed an effective breakdown of design responsibilities. Supplementing the capstone team with underclassmen completing an independent study was used to back fill requirements for the construction phase, and aids in continuity of the project. Volunteers were essential for casting day when a large amount of work was completed in a short period. For a five-member student team, the roles assigned were project manager, hull designer, structural engineer, mix designer, and construction manager. On a six-student team the sixth person served as the materials researcher working closely with the mix designer. The difference in roles between the mix designer and materials researcher needed to be clearly defined to still provide a way to conduct an individual assessment. Although the materials researcher could have supported any team member, the teamwork observed with the mix designer proved invaluable to develop a unique concrete mix.

The project manager was responsible for the project schedule, procurement of materials, external communication, and internal coordination. During the first semester, the solve and design deliverable for the project manager was the project schedule. The initial project schedule was developed before the Request for Proposal (RFP) was released by ASCE using the knowledge of previous year's competition timelines [17]. Finalizing the project schedule was iterative as the team made decisions on material use and construction methods, such as the mix design and construction mold. The project manager accounted for lead time for material delivery and varying levels of experience/progress of each team members during updates. The project manager was also required to complete the project management section of the competition's technical proposal, which is due in February. This was used to assess written communication and their ability to solve. The project management section requires discussion on Key Team Roles and Organization, Project Scope, Health and Safety, a Project Management Plan, Quality Assurance and Quality Control (QA/QC), Research and Development Cost, and Project Schedule [17]. One of the course-wide deliverables was an Interim Progress Review (IPR). The IPR was used to assess oral communication. The project manager was assessed during the IPR on their ability to orally communicate the project schedule, risks, and risk mitigation to an external audience. The student outcome of acquiring and applying new knowledge was assessed at the start of the semester. The project manager was required to research project management methods that they had not received in previous courses in curriculum. The project manager selected at least one new technique to implement in the project and wrote a two-page essay explaining the technique and their plan for implementation. The project manager was assessed throughout the semester on the effectiveness of implementing the selected technique. To assess teamwork, the Concrete Canoe team completed a Comprehensive Assessment of Team Member Effectiveness (CATME) survey at both mid-semester and end of the semester [26]. The course wide IPR and CATME survey were used to assess oral communication and teamwork for all team members.

The hull designer was responsible for developing the geometry and key dimensions of the canoe hull. A 3D SolidWorks model of the hull was developed to facilitate the construction of the canoe mold. The hull designer sought input from the team on their performance objectives. Hull design was not addressed in the civil engineering curriculum, so the hull designer began with a literature review on boat and canoe features that the team identified were critical including stability, maneuverability, and decreased drag. The literature review was assessed as the new knowledge student outcome. The hull designer selected the dimensions, shape, and features such as a keel, rocker, or chines to help with maneuverability and stability. The design process was iterative as the hull designer received feedback from the structural engineer and mix designer on capabilities or limitations. The outcome of the student's ability to design was assessed based on the final SolidWorks model of the canoe. The hull designer documented their process, performance objectives, and results within the Technical Design and Construction Support portion of the technical proposal [17]. The hull design portion of the technical proposal was assessed as the written communication deliverable. The final hull design combined with the technical proposal were used to assess the solve student outcome.

The mix designer was responsible for developing a concrete mixture that met both the requirements of the RFP and the team's established goals. In the Civil Engineering curriculum, students were introduced to mix design during the laboratory portion of the Design or Reinforced Concrete course, but the course did not go into great depth on mix design. The mix designer began with a literature review about the effects and properties of different supplementary cementitious materials in both the fresh and hardened state, lightweight aggregates, and the use of chemical admixtures to assess the new knowledge student outcome. The mix designer identified key properties in an acceptable mix; most notably in the fresh state to cast the canoe and in the hardened state to achieve the desired mechanical properties and finish. If the team had a sixth member, the mix design responsibility was shared by two team members with one member focusing on mineral admixtures or supplementary cementitious materials and one team member focusing on the use of chemical admixtures. The mix design team started with an initial concrete mixture based off the results of the literature review and the success of previous teams. Fresh properties such as slump, air content, and unit weight were tested in accordance with ASTM C143, ASTM C138, and ASTM C173 respectively. Compressive strength was tested at seven and twenty-eight days in accordance with ASTM C39. Using the unit weight and seven-day strength as initial indicators, modifications were made to the mixture to optimize specific material properties. The design and solve outcomes were assessed based on the final mix design worksheet included in the technical proposal. The mix design portion of the technical proposal assessed written communication.

The structural engineer was responsible for ensuring the final hull design and mix design were sufficient to meet the structural requirements of the canoe for all loading conditions including transportation, display, the two-person race, four-person race and all local failure modes such as one way shear, punching shear, flexure, and combined loading. Using the minimum compressive and tensile strength of the final concrete mixture, the structural engineer calculated the required thickness of the canoe. The structural engineer also designed the tensile reinforcement. The design and solve student outcomes were assessed based on final structural calculations. The structural engineer used American Concrete Institute Code 318-19 to determine one way and two-way shear strength and the equivalent rectangular stress block to determine moment capacity [27]. To assess written communication, the structural engineer completed the structural analysis portion of the technical proposal. Acquiring and applying new knowledge was assessed by failure envelope analysis structural calculations which was not covered in the Design of Reinforced Concrete course.

The construction manager's responsibilities focused on construction of the canoe mold and sequencing of cast day construction activities. The construction manager conducted a literature review of other teams' proposals from previous years and selected a few innovative construction techniques. A two-page essay outlining the innovative techniques was used to assess the new knowledge student outcome. Using the hull design SolidWorks model, the construction manager designed construction strategies considering male versus female molds, form materials, and demolding procedures. The construction manager also developed the method for casting including QA/QC checks, uniform layers placement, and reinforcement placement. A final cast day construction plan and mold design assessed for the design and solve student outcomes. The technical proposal included a section for Construction Process which assessed written communication.

Assessment of the ABET student outcomes during the project's second semester was more difficult because most of the design requirements were complete. Some roles were adjusted to meet the needs of incomplete requirements. The hull and mix designs were completed. These members of the team shifted their focus to engineering challenges such as transportation of the canoe to the competition and creation of the display to accompany the prototype at competition. The project manager's role remained unchanged. The structural engineer maintained their role, but responsibility shifted focus to load conditions experienced during finishing, transportation, and display. The construction manager designed an apparatus to transport the canoe.

Additional project specific deliverables included rowing practice, team building exercises, team workouts, creation of continuity files, and a branding/marketing plan. Because the concrete canoe competition is designed to simulate competing to win a bid to mass produce concrete canoes, the branding and marketing plan's importance was evident in the prototype display, technical proposal, and technical presentation. Parallelling the world of business, project specific points could be allocated to success at the regional competition and being awarded the "contract." In some cases, these additional requirements were used as supplemental assessments of the ABET student outcomes.

Results

The capstone course spanned two semesters. The specific graded requirements for each semester varied, but the breakdown between course-wide requirements and project requirements was consistent. Each semester, 40% of the students' grade was assigned to the advisor's assessment of the ABET student outcomes of design, solve, written communication, oral communication, new knowledge, and teamwork. Of the remaining 60%, 25% was assigned to course-wide deliverables and 35% were project specific. The project specific requirements included the initial project contract between the student team and the advisor, a project schedule, a presentation to new civil engineering majors, the midterm IPR, and an end of term report. The project specific deliverables were agreed upon by the students and the advisor in the written contract at the start of each semester. The assessment of individual student outcomes was completed both qualitatively and quantitatively. For the quantitative assessment of individual student outcomes, an individual deliverable was provided by each team member based on their role. The breakdown of individual assignments is shown in Table 1 for Steel Bridge and Table 2 for Concrete Canoe. The qualitative assessment was completed using the format of an employee appraisal form [19]. A sample of the "Capstone ABET Outcome Support Form" is shown in Appendix A. The capstone support form provided a chance for dialogue between the advisor and the student regarding perceived effort and performance. It also served as a mentoring opportunity to discuss specific technical requirements and professional practices. Each team member was required to identifying personal goals early in the project, and later linking accomplishments to the stated goals.

Deliberately assigning specialized team roles was not found to significantly impact individual assessment of student outcomes. The capstone support form made it easy to assess individual contributions to group deliverables such as oral presentations and final reports. It is worth noting that application of new knowledge did not diminish with increase in the individual or the collective team expertise within the competition gained in previous years. Rather, a higher level of knowledge was achieved by additional experience with construction, software application, and design calculations. The quality of the design products produced by experienced members of the team greatly increased. Therefore, when each member was held accountable, a similar level of improvement in the student outcomes of solve, design and application of new knowledge was observed in both experienced and new team members.

TEAM ROLE/ ABET OUTCOME	PROJECT MANAGER	STRUCTURAL ENGINEER	CONNECTION DESIGNER	FABRICATION LEAD	DRAFTER
DESIGN	• 2D Conceptual Designs • Project Schedule	• 2D Conceptual Designs • Optimized Structural Design	• 2D Conceptual Designs • Final Connections	• 2D Conceptual Designs • Construction Plan	• 2D Conceptual Designs • CAD Model
SOLVE	• Mini Bridge Competition • Project Schedule • Experimental Test	• Mini Bridge Competition • Structural Analysis Model • Experimental Test	• Mini Bridge Competition • Finite Element Model • Experimental Test	• Mini Bridge Competition • Material Selection • Fabricated Bridge • Experimental Test	• Mini Bridge Competition • Shop Drawings • Experimental Test
COMMUNICATION (WRITTEN)	• Final Report	• Final Report	• Final Report	• Final Report	• Final Report
COMMUNICATION (ORAL)	• IPR • Final Technical Presentation	• IPR • Final Technical Presentation	• IPR • Final Technical Presentation	• IPR • Final Technical Presentation	• IPR • Final Technical Presentation
NEW KNOWLEDGE	• Project Management Innovation • Steel Fabrication	• Structural Analysis Software • Steel Fabrication	• Finite Element Modeling • Steel Fabrication	• Steel Fabrication • Fabrication Innovation	• 3D CAD Modeling • Steel Fabrication
TEAMWORK	• Daily Briefings • Peer Review	• Daily Briefings • Peer Review	• Daily Briefings • Peer Review	• Daily Briefings • Peer Review	• Daily Briefings • Peer Review

Table 1: Steel Bridge Student Outcome Deliverables

TEAM ROLE/ ABET OUTCOME	PROJECT MANAGER	HULL DESIGNER	STRUCTURAL ENGINEER	MIX DESIGNER	MATERIALS RESEARCHER	CONSTRUCTION MANAGER
DESIGN	• Project Schedule	• Hull Design • Competition Display	• Structural Calcs • Transportation Structural Calcs	• Mix Design Worksheet (SCMs) • Transportation Plan	• Mix Design Worksheet (Chemical Admixtures) • Canoe Finishing Plan	• Construction Plan • Mold Design • Transportation Plan
SOLVE	• Design • Technical Proposal	• Design • Technical Proposal	• Design • Technical Proposal	• Design • Technical Proposal	• Design • Technical Proposal	• Design • Technical Proposal
COMMUNICATION (WRITTEN)	• Technical Proposal	• Technical Proposal	• Technical Proposal	• Technical Proposal	• Technical Proposal	• Technical Proposal
COMMUNICATION (ORAL)	• IPR • Final Technical Presentation	• IPR • Final Technical Presentation	• IPR • Final Technical Presentation	• IPR • Final Technical Presentation	• IPR • Final Technical Presentation	• IPR • Final Technical Presentation
NEW KNOWLEDGE	• Project Management Innovation • Research and Development Cost Breakdown	• Hull Design Innovation • Marketing Plan	• Mohr's Circle & Punching Shear Calculations • Research on transportation of canoe	• Mix Design Innovation (SCMs and Aggregates) • Marketing Plan	• Mix Design Innovation (Chemical Admixtures) • Canoe Finishing Plan	• Casting Innovation • Research on transportation of canoe
TEAMWORK	• CATME Survey	• CATME Survey	• CATME Survey	• CATME Survey	• CATME Survey	• CATME Survey

Table 2: Concrete Canoe Student Outcome Deliverables

Conclusions

This paper presented a framework for educators to implement student design competitions, specifically the AISC SSBC and the ASCE Concrete Canoe Competition, as culminating capstone design projects. The framework presented in this manuscript will help educators document student team members individual ABET student outcomes. Each competition included a combination of group and individual assignments. These individual assignments were assessed both quantitatively based on a deliverable and qualitatively based on the student's development through the project. Specific assignments were directly tied to each outcome. The students were made aware that these assignments were used to measure the development of their technical skills through their engineering curriculum. For qualitative assessment of individual student outcomes, the capstone support form gave advisors the opportunity to mentor students and give them feedback on their performance. The ABET criterion requires that faculty "develop and implement processes for the evaluation, assessment, and continuing improvement of the program" [1]. The processes presented in this paper may be used by other institutions to realize the educational benefits of society sponsored design competitions.

Future work

The authors recognize the limitations of this study as a detailed assessment of program has not been presented. Future research will investigate the quality of design-build competition capstone projects compared to other capstone projects offered at the United States Military Academy. This will be assessed by surveying students and external stakeholders who attend the final presentations for all capstone projects. The project will assess the educational value of student competitions, the design process, and individual contribution of members. The authors will also investigate the execution of the SSBC and Concrete Canoe Competition at other institutions. Specifically, the authors will compare teams which complete the project as an extra-curricular club or a course requirement. The authors also hope to evaluate the implementation of a hybrid approach, where the project is implemented as a single semester paper-based design.

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Appendix A: ABET Student Outcome Assessment Form

CAPSTONE ABET OUTCOME SUPPORT FORM

PART I - ADMINISTRATIVE (Rated Cadet)

a. NAME *(Last, First, Middle Initial)*

g. CAPSTONE TEAM

j. RATED CADET'S EMAIL ADDRESS *(.gov or .mil)*

PART II - AUTHENTICATION

a1. NAME OF HEAD ADVISOR *(Last, First, Middle Initial)*	RANK	EMAIL ADDRESS *(@westpoint.edu)*
b1. NAME OF CO-ADVISOR *(Last, First,Middle Initial)*	RANK	EMAIL ADDRESS *(@westpoint.edu)*
c1. NAME OF CO-ADVISOR *(Last, First,Middle Initial)*	RANK	EMAIL ADDRESS *(@westpoint.edu)*

PART III - VERIFICATION OF FACE - TO - FACE DISCUSSION

CADET/ADVISOR INITIAL FACE-TO-FACE COUNSELING ON DUTIES, RESPONSIBILITIES AND PERFORMANCE OBJECTIVES FOR THE CURRENT RATING PERIOD TOOK PLACE ON (DATE) ___________ CADET INITIALS __________ ADVISOR INITIALS __________

PERIODIC CADET/ADVISOR FOLLOW-UP FACE-TO-FACE COUNSELINGS:

DATE__________ CADET INITIALS __________ ADVISOR INITIALS__________

DATE__________ CADET INITIALS __________ ADVISOR INITIALS__________

DATE__________ CADET INITIALS __________ ADVISOR INITIALS__________

PART IV - RATED OFFICER - DUTIES AND RESPONSIBILITIES

a. PRINCIPAL DUTY TITLE:	b. ADDITIONAL DUTY TITLE:

c. LIST THE CAPSTONE TEAM GOALS

d. STATE YOUR SIGNIFICANT DUTIES AND RESPONSIBILITIES:

PART V – ABET STUDENT OUTCOMES AND ACCOMPLISHMENTS

a. INDICATE YOUR MAJOR PERFORMANCE OBJECTIVES:	b. LIST SIGNIFICANT CONTRIBUTIONS AND ACCOMPLISHMENTS:

PART V -ABET STUDENT OUTCOMES AND ACCOMPLISHMENTS CONTINUED

A. SOLVE - an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.

INDICATE YOUR MAJOR PERFORMANCE OBJECTIVES:

LIST SIGNIFICANT CONTRIBUTIONS AND ACCOMPLISHMENTS:

B. DESIGN - 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.

INDICATE YOUR MAJOR PERFORMANCE OBJECTIVES:

LIST SIGNIFICANT CONTRIBUTIONS AND ACCOMPLISHMENTS:

C. WRITTEN COMMUNICATION - communicate effectively with a range of audiences (based on West Point Writing Program).

INDICATE YOUR MAJOR PERFORMANCE OBJECTIVES:

LIST SIGNIFICANT CONTRIBUTIONS AND ACCOMPLISHMENTS:

D. ORAL COMMUNICATION - communicate effectively with a range of audiences.

INDICATE YOUR MAJOR PERFORMANCE OBJECTIVES:

LIST SIGNIFICANT CONTRIBUTIONS AND ACCOMPLISHMENTS:

E. 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.

INDICATE YOUR MAJOR PERFORMANCE OBJECTIVES:

LIST SIGNIFICANT CONTRIBUTIONS AND ACCOMPLISHMENTS:

F. APPLY NEW KNOWLEDGE - acquire and apply new knowledge as needed, using appropriate learning strategies.

INDICATE YOUR MAJOR PERFORMANCE OBJECTIVES:

LIST SIGNIFICANT CONTRIBUTIONS AND ACCOMPLISHMENTS:

PART VI – ADVISOR COMMENTS

CADET -SIGNATURE AND DATE:

Continuation Section

PARTS I-IV INSTRUCTIONS.

Some key **requirements: The advisor will** --

a. Discuss the scope of the rated cadet's duty description with him or her within 1 week of the capstone teams contract being due. This counseling will include, as a minimum, the rated cadet's duty description and the performance objectives to attain. The discussion will also include the relationship of the duty description and objectives with the team's mission, problems, priorities, and similar matters.

b. Advisors will conduct follow-up counseling sessions to discuss performance, update and/or revise developmental tasks, as required, and assess developmental progress. Summary or key comments will be recorded.

The rated cadet plays a significant role in counseling sessions and the evaluation process throughout the semester.

PART V INSTRUCTIONS: ICW ADRP 6-22 and ADP 6-0 rated officer performance objectives will align with the attributes and competencies required for all officers. The overall definition of each attribute and competency is addressed in the base support form. Key points:

Civil Engineering Student Outcome		Outstanding (5)		Very Good (4)	Good (3)	Fair (2)	Poor (1)
		A+ (x >=96.67%)	**A** (93.33% <= x < 96.67%)	**A- / B+** (86.67% <= x < 93.33%)	**B / B-** (80.00% <= x < 86.67%)	**C+ / C / C-** (70.00% <= x < 80.00%)	**D / F** (x < 70.00%)
SOLVE	**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. Engaged with and exceeded all project criteria. Professional standards exceeded in all areas.	Problem clearly identified with no assistance. Well above average technical and creative solution. Consistently engaged with and exceeded project criteria. Professional standards exceeded in mostareas.	Problem clearly identified with some assistance. Strong technical and/or creative solution. Consistently engaged with 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 not met in some areas.	Failed to identify problem effectively. Sub-standard technical solution with little to no creativity. Failed to meet the project criteria. Professional standards not met in most areas.
DESIGN	**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 areas of design needs/considerations. Produced solutions that met all identified areas. Solutions exhibited exceptional technical understanding and breadth.	Appropriately identified all areas of design needs/considerations. Produced solutions that met all identified areas. Solutions exhibited strong technical understanding.	Appropriately identified all areas of design needs/considerations. Produced solutions that met most areas. Solutions exhibited good technical understanding.	Appropriately identified most areas of design needs/considerations. Produced solutions that met most areas. Solutions exhibited average technical understanding.	Failed to identify some areas of design needs/considerations. Solutions did not meet all areas. Solutions exhibited limited technical understanding.	Failed to identify areas of design needs/considerations. Failed to produce solutions for most areas. Solutions exhibited little to no technical understanding.
COMMUNICATE	**(WRITTEN) COMMUNICATE effectively with a range of audiences. (based on the West Point Writing Program)**	*Exemplary* in all areas: 1. Substance 2. Organization 3. Style & Presentation 4. Mechanics & Correctness 5. Documentation	*Exemplary* in at least three areas and *Satisfactory* in all others: 1. Substance 2. Organization 3. Style & Presentation 4. Mechanics & Correctness 5. Documentation	*Exemplary* at least two areas and *Satisfactory* in all others: 1. Substance 2. Organization 3. Style & Presentation 4. Mechanics & Correctness 5. Documentation	*Satisfactory* or better all areas: 1. Substance 2. Organization 3. Style & Presentation 4. Mechanics & Correctness 5. Documentation	*Marginal* or better in all areas: 1. Substance 2. Organization 3. Style & Presentation 4. Mechanics & Correctness 5. Documentation	*Not Proficient* in at least one area: 1. Substance 2. Organization 3. Style & Presentation 4. Mechanics & Correctness 5. Documentation
	(ORAL) COMMUNICATE effectively with a range of audiences.	Well-rehearsed and professional presentation of technically exceptional content. Performed well above peer presentations	Well-rehearsed and professional presentation of technically rigorous 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.
TEAM	**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: C – Contributing to the team's work I – Interacting with teammates K – Keeping the team on track E – Expecting Quality H – Having related knowledge, skills, and abilities	Exemplary in most areas: C – Contributing to the team's work I – Interacting with teammates K – Keeping the team on track E – Expecting Quality H – Having related knowledge, skills, and abilities	Exemplary in two areas and satisfactory in all others: C – Contributing to the team's work I – Interacting with teammates K – Keeping the team on track E – Expecting Quality H – Having related knowledge, skills, and abilities	Satisfactory or better all areas: C – Contributing to the team's work I – Interacting with teammates K – Keeping the team on track E – Expecting Quality H – Having related knowledge, skills, and abilities	Marginal or better in all areas: C – Contributing to the team's work I – Interacting with teammates K – Keeping the team on track E – Expecting Quality H – Having related knowledge, skills, and abilities	Not proficient in at least one area: C – Contributing to the team's work I – Interacting with teammates K – Keeping the team on track E – Expecting Quality H – Having related knowledge, skills, and abilities
NEW KNOWLEDGE	**Acquire and apply NEW KNOWLEDGE as needed, using appropriate learning strategies.**	Exceptionally detailed review of existing work is completed. Enthusiastically engaged in learning new material, beyond the scope of the project. Exceeded expectations and performed well above peers.	Detailed review of existing work is completed. Engaged in learning new material, beyond the scope of the project. Exceeded expectations.	A review of existing work is completed. Fully engaged in learning new material across required aspects of the project. Met expectations.	An incomplete review of existing work iscompleted. 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 acquire and apply new knowledge.