



## **A Construction Management Competition as the Basis of a Capstone Culminating Event**

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Culminating design events serve as a hallmark of most undergraduate engineering programs. This paper presents a case study of a novel approach to conduct a compressed-timeframe culminating event just prior to graduation. The event is designed to leverage best practices in literature related to team-building, competitions, student leadership, real-project case studies, and high-impact practices. The culminating event takes place at the conclusion of a two-semester capstone sequence. In the middle of this two-semester sequence, 12 students from a class of roughly 40-50 participate in the intercollegiate Associated Schools of Construction (ASC) competition. The ASC competition then serves as the model for the culminating event, in which these 12 students leverage their experience to assume a leadership role among their peers. Near the end of the second semester, students transition from their traditional capstone course sequence to a culminating design event. During this transition, the 12 students who participated in the ASC competition form teams of 12-15 students each, which they will lead as they compete academically to “win” a design-build contract for a real project. Teams integrate students’ experiences from four sub-disciplines represented in the major: construction, environmental, geotechnical, and structural engineering. Additionally, both faculty members and industry advisors serve as mentors and coaches. The event climax is an intensive one week work period that simulates the construction industry environment they will experience after graduation. During this sprint to the finish, students complete their design and construction plans, assemble their final deliverables, and brief a panel of judges to include real project stakeholders. The paper outlines assessment of both the event and the student deliverables, with linkages to ABET outcomes. This case study should prove useful to educators exploring innovative approaches to their capstone course, those looking to conduct a culminating event in a compressed timeframe, as well as those interested in providing leadership development opportunities for graduating engineers.

### **Introduction**

Culminating design events serve as a hallmark of most undergraduate engineering programs [1], [2], and many undergraduate programs leverage a quarter, semester, or even yearlong capstone course to meet this objective. This paper presents a case study of a novel approach to conduct a compressed-timeframe culminating event just prior to graduation, in the context of a two-semester capstone sequence.

The culminating event is designed to leverage best practices in literature related to team-building, competitions, student leadership, real-project case studies, and high-impact practices. Literature related to these practices is embedded throughout the paper as it describes the overall structure and design. The event also helps achieve objectives related to ABET accreditation, which requires “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” [3].

The following section provides the university and departmental context for the competition, followed by a description of the industry-sponsored intercollegiate competition that inspired its design. The paper then lays out how an undergraduate civil engineering program adapted the competition for their culminating event, with planning and execution conducted in four phases. The paper concludes by discussing lessons learned as well as assessment of both the event and the student deliverables, with linkages to ABET outcomes.

## **University and Program Context**

The setting for this program is the United States Air Force Academy (USAFA), whose mission is to “educate, train, and inspire men and women to become leaders of character” [4]. Upon graduation, students are commissioned as Air Force officers in a variety of career fields in service to the nation. The Air Force Academy’s curriculum is designed to provide a “broad liberal education while also providing our cadets with the best possible preparation for a lifetime of service to the Nation” [5]. To provide this broad liberal education, the institution implemented a core curriculum consisting of 93 semester hours spread across course offerings in humanities, social sciences, engineering, and basic sciences, in addition to five semester hours of physical education. While, the culminating event described below could be adapted to any university, the context of a service academy offers additional motivation for leveraging aspects of competition and leadership.

The school’s civil engineering major requires 45 semester hours of major’s coursework on top of the robust core curriculum of 93 credit hours. The department offers courses in four primary sub-disciplines which are referenced throughout this paper: construction, environmental, geotechnical, and structural engineering, taken primarily in the junior and senior years.

These majors’ courses are framed by two high-impact events, which serve as the showcase events for the curriculum (Figure 1). Kuh [6] argues for high impact practices (HIPs) in the curriculum and advocates for one in the first year and one in the majors curriculum that occurs later. Although not in the first year due to the large core curriculum requirements, the department offers one HIP at the start of the major, and one at the end of the senior year.

The first HIP occurs during a three week period in the summer between the sophomore and junior year, Civil Engineering 351: Civil Engineering Practices – Field Engineering. The course is required for all civil engineering majors and is affectionately referred to as “FERL” since it is held at the department’s 50-acre Field Engineering and Readiness Laboratory (FERL) site. Although it may seem counterintuitive at first, the FERL motto “Construct First, Design Later” conveys its experiential-learning objectives. The course is considered the “cornerstone” of the civil engineering degree since it is accomplished early in the major’s course sequence and allows cadets to perform a variety of hands-on construction and engineering activities [7]. These activities are then referenced in the classroom for the next two years of design courses. Dym et al. [8] advocate for a cornerstone course in engineering education and note the benefits of

performing design activities early in the curriculum sequence. Students reside on-site for the three week course, which enables students to form a tight cohort through this immersive experience that last throughout their education and often beyond graduation. Fink [9] notes that creating a sense of community can significantly increase the quality of the learning experience.

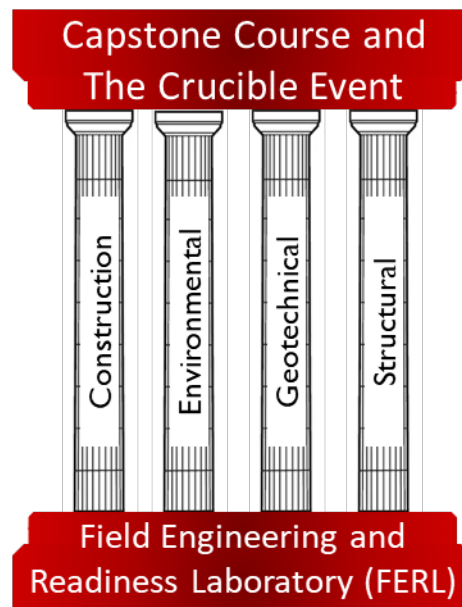


Figure 1. Program Structure with High Impact Practices

As suggested by Bain [10] the USAFA civil engineering program encourages students to try first (in FERL), learn the theory and receive feedback (in major's courses) and try again (in their capstone experience). The remainder of this paper will discuss the case study of a capstone design competition held near the end of the senior year, which serves as the second HIP for the program.

### **Basis for Culminating Event: Associated Schools of Construction Regional Competitions**

To deliver this high-impact event at the close of the curriculum, faculty designed an intense competition modelled after the Associated Schools of Construction (ASC's) Regional Competitions. ASC's competition is similar to other well-known student competitions, such as: the American Society of Civil Engineers' (ASCE) concrete canoe, the Society of Automotive Engineers' (SAE) mini-Baja, and the Institute of Electrical and Electronics Engineers (IEEE) competitions. Khorbotly et al. [11] describes multiple benefits of participating in these competitions, to include improving teamwork, communication, and leadership skills. Similarly, Walden et al. [12] argue that competition teams are a prime opportunity for students to gain professional skills related to leadership and management, although they found that some competition teams often fail to take advantage of these opportunities.

More specifically, the culminating event, known as “The Crucible,” is modelled after ASC’s Design-Build competition, one of several competition categories that students may compete in each year (others include commercial construction, mechanical systems, heavy civil, etc.). ASC’s Design-Build competition requires teams to develop a conceptual design and several pre-construction documents from an actual project built by an industry sponsor. Previous competitions have included projects such as new construction of a high-school performing arts center, an aquarium, and several higher-education facilities.

Similar to an actual design build project, teams must provide deliverables in the first phase as part of a response to a Request for Qualifications (RFQ), although without knowing what the project will be. In the second phase, teams respond to a Request for Proposals (RFP) after learning the details of the project. This second phase of the competition occurs entirely on-site at a large conference venue. The project and RFP are released by the industry sponsor around 7:00 am with final written deliverables being due the same day around 10:00 pm. Among the most important written deliverables is a design approach that meets owner specifications. The student-generated designs involve a 3D conceptual building design with floor plans, elevations, and renderings. Other elements include preconstruction planning documents such as preliminary schedule, cost estimate, and site utilization plan. After delivering their written deliverables in the evening, teams then give an oral presentation the following day to the panel of industry judges.

Participating in this intense competition offers significant benefits for the civil engineering program. First, a portion of the program’s graduates gain valuable exposure to industry problems and strengthen their design, construction, and project management expertise. Second, the department benefits from networking with similar programs in the region. Third, and most applicable for this paper, the department gains a core set of student leaders who will serve a critical role in the department’s culminating design event known locally as The Crucible.

### **Framework for the Culminating Event**

While The Crucible takes place late in a compressed timeframe during the spring semester each year, the event is part of a longer two-semester capstone sequence. The planning and execution of the capstone sequence which has five components, as shown in Figure 2.

The sequence begins with students enrolling in a technical design elective during fall of their senior year from one of the major’s four sub-disciplines outlined previously in Figure 1. In this phase, students develop depth of knowledge that can be leveraged in the following semester.

The second component begins in the spring semester, when students enroll in a required project management course that also serves as the second half of their capstone sequence. In this course, students learn about managing an owner’s project throughout the project life-cycle, covering topics such as a life cycle cost analysis, engineering economics, design development, construction oversight, and asset management. Within this course, students develop a conceptual

design for a new facility, which helps hone their skills in tying together all four sub-disciplines prior to the Crucible.

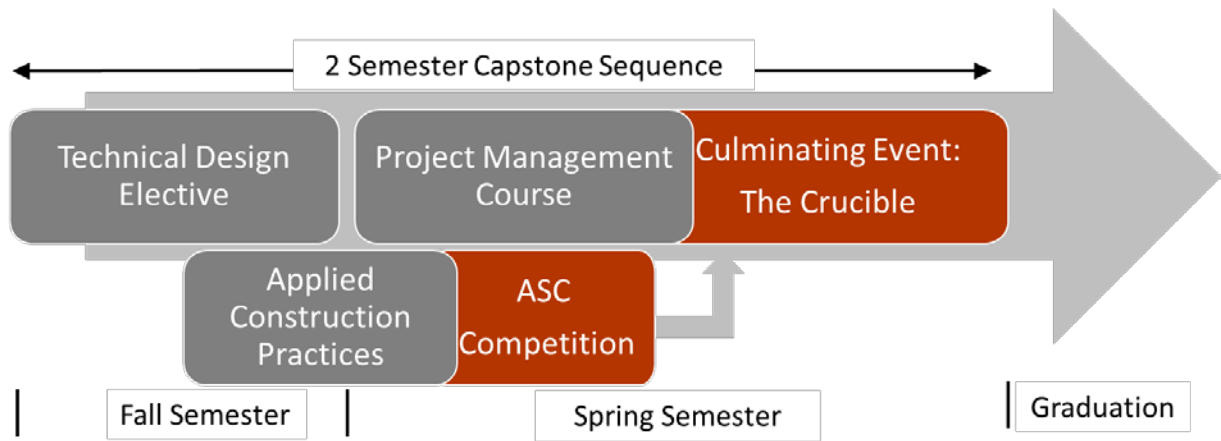


Figure 2. Capstone Sequence and Timing

The third component consists of recruiting 12 seniors and two juniors in good academic standing to compete in the Associated Schools of Construction regional competition. The department enrolls these 14 students in a 3-hour credit course, Applied Construction Practices, that bridges the fall and spring semesters. The students spend the second half of the fall semester learning about the competition, reviewing previous problems, and forming their teams. They form two teams of six, plus one alternate each. The alternates are the two juniors who will take leadership roles on the teams the following year. In the beginning of the spring semester, students practice additional problems and finalize preparations for the actual competition (fourth component) which typically occurs in February, as described in the previous section. After returning from the competition, students submit after-action reports and organize their competition documents for use by future years' teams.

### **Culminating Event: “The Crucible”**

The fifth and final component, shown at the right of Figure 2, is the climax of the capstone sequence, the phase known as The Crucible. The image of a crucible is one that melts and refines metal, transforming it into a stronger substance, an image that works well in a service academy setting. Thus, the event is designed to be an intense learning experience that tests and improves one's strength. In this case, the test is more mental or academic than physical in nature, helping students integrate and strengthen their various design experiences similar to an alloy that is stronger than its component metals. The Crucible thus: synthesizes the students' coursework as they see a multidisciplinary project come together, further prepares them for what they'll be doing after graduation; and gives them a confidence boost in the skills they've learned in their civil engineering program.

Prior to the competition, the twelve seniors who competed in the ASC Competition are reorganized into 4-5 new teams. They will serve as team leaders (2-3 each) of their new teams,

which consist of 12-15 total members depending on the number of seniors. By allowing the students to form and lead the teams, they gain valuable insights on peer leadership, consistent with the university's mission to develop leaders of character. Several authors note that educational experiences that entail working with a group of peers have the benefit of building bonds among the team members which stimulates enthusiasm and leads to a better appreciation of the learning experience, e.g. [13], [14]. Thus, the department sought to gain these benefits with both the cornerstone (FERL) and capstone (Crucible) portions of the curriculum.

During team member selection, team leaders must create a balanced team of students with a mix of experience in the department's four areas of emphasis: construction, environmental, geotechnical, and structural. Faculty provide course enrollments of key design options to help inform their team building. Team leaders take turns "drafting" their peers until every student has been selected. At this point of the 4-year curriculum, the student leaders tend to know their peers quite well as a result of the hands-on immersion experience at FERL (described previously) and co-enrollment in numerous course offerings. This knowledge helps create balanced teams which is critical to ensuring healthy competition in the fourth phase.

During the competition, teams assume the identity of a design-build firm, dividing up individual roles by sub-discipline as outlined previously. Team leaders are charged with providing overall guidance and ensuring the final products reflect a fully coordinated design and construction plan between sub-disciplines. Teams compete to "win" the job by having the most technically sound approach and best integrated design.

Examining Table 1 highlights a few important similarities between The Crucible and the ASC design-build competition. For example, both use case studies of real projects, a practice well established in capstone courses and engineering education literature, e.g. [15]–[17]. Students often have innovative ideas and in some cases, their feedback is provided to the project owner and can influence the real project. Given that the course is hosted at a military service academy, the faculty use their contacts within the service to generate a problem based on a Department of Defense military construction project. Recent Crucible projects have included office buildings, aircraft hangar facilities, and airfield parking aprons. Both competitions also have some similar deliverables as related to architectural and construction planning, such as an architectural design, a cost estimate, and detailed schedule.

Reviewing Table 1 also reveals a few important differences between The Crucible and the ASC design-build competition. First, the timeline is extended over a week for the Crucible (versus one day for ASC) because teams are larger and are charged with submitting more design deliverables. Some of the additional deliverables are tied to the need to integrate multiple civil engineering disciplines. For example, students may be designing foundations, structural members, retaining structures, storm water management systems, and/or a remediation system for a contaminated site.

Table 1. Comparison of Student Competitions: ASC and The Crucible

<b>Characteristic</b>	<b>ASC Competition</b>	<b>The Crucible Competition</b>
<b>Student Team Size</b>	6	12-15
<b>Type of Project</b>	Real-world, design-build, new construction	Real-world, design-build, new construction
<b>Deliverables</b>	Written response to RFQ and RFP plus oral presentation	Written response to RFQ and RFP plus oral presentation
<b>Design Requirements</b>	Primarily architectural with supporting construction plans	Architectural, geotechnical, environmental, structural with supporting construction plans
<b>Timeline</b>	Qualifications due in advance; Proposal development in 14 hours Oral presentation next day	Qualifications due in advance; Proposal development in 7 days Oral presentation final day
<b>Role of Industry</b>	Sponsors project and judges student work; no advising during competition	Advises students during competition; judges panel may have one industry member
<b>Role of faculty</b>	Coach the team in advance; no advising during competition	Available through RFIs and appointments during competition

Another important distinction between the Crucible and ASC is the use of industry advisors during the competition. ASC teams usually have industry advisors, and sometimes sponsors, that may help prepare their students for the competition in advance. During the one-day competition event, no outside collaboration or advice is allowed by industry or faculty members. However during the Crucible, both faculty and industry members consult with students to act as a sounding board, but do not direct their specific design solutions. Student teams may submit requests for information (RFIs) from the faculty, and the answers will be provided to all teams, similar to RFIs a real construction project procurement process. Department faculty also recruit industry representatives from civilian design and/or construction firms, who are available to the student teams at key points in the Crucible timeline. Finally, a joint panel of faculty and industry advisors, to include the real project owner, serve as judges for the competition as further explained in the following section.

### **Assessment of Culminating Event**

The panel of judges typically consists of 2-3 faculty members, an industry advisor, and a representative from the owner's organization that sponsored the project being used. These judges primarily evaluate the oral presentation as well as the question and answer session that follows. Presentations constitute about 25% of the overall team score and are later combined with the written deliverable assessments that make up the bulk of the team score (Table 2). The team with the highest score "wins" the job, and the competition.

While teams are giving their presentations, another panel of faculty members is busy grading elements of the written deliverables. The deliverables are first divided among faculty according to discipline to evaluate the technical approach to various elements of each discipline: construction, environmental, geotechnical, and structural. Then 1-2 faculty members assess how



well all of these elements are integrated into an overall design approach. In total, as the event involves all seniors in the program, it all requires an “all hands on deck” approach for faculty.

Table 2. Scoring Breakdown for The Crucible Student Competition

<b>Characteristic</b>	<b>ASC Competition</b>	<b>Points</b>
<b>Written Deliverables</b>	Qualifications Package (RFQ)	10
	Architectural Design	20
	Environmental Design	15
	Foundation Design	15
	Structural Design	15
	Site Plan	15
	Sustainability	5
	Cost Estimate	10
	Schedule	10
	Writing/Professionalism	5
	<b>Oral Presentation</b>	Group Presentation
<b>Team Score Total</b>	<b>Subtotal</b>	<b>160</b>
<b>Individual Score</b>	<b>Individual Effort</b>	<b>40</b>
<b>Total Student Score</b>		<b>200</b>

Team competition scores constitute the majority of an individual’s grade for the event, but each student also receives an individual grade for their portion of the work. Individual grades are based on a recommended rating from fellow student leaders, who are provided a rubric to use as a starting point. Faculty assess the student leaders’ ratings and work with them to make adjustments if necessary. Final grades from the Crucible (individual plus group) represent 25% of a student’s overall grade from the three-credit hour course Civil Engineering 480, Project Management and Contract Administration.

Beyond assessment for a single course, the department also uses Crucible scores to assess a portion of its Student Outcomes, which have historically matched ABET’s Student Outcomes [3]. A sample assessment (Table 3) shows how elements of the competition are used to help assess three specific Student Outcomes under ABET Criterion 3. The department establishes a minimally acceptable standard such as a 70% average, and then calculates the average score for each graded component under that standard (example metrics provided). The primary value of these scores is not in the numbers themselves but in tracking changes in scores from one year to the next. Of note, these scores are not the only events used to assess any given Student Outcome, but are combined with metrics from other courses in the four-year curriculum.

### **Adjustments and Lessons Leaned**

After its conclusion, the lead instructor provides a written Course Assessment Report each year to capture lessons learned, which drive changes for the following year. Additionally, students provide feedback to the department anonymously about the program through focus groups and exit surveys, to include their capstone experience. The Crucible has made several

Table 3. Crucible Assessment Linkage to Student Outcomes

Student Outcome	Standard	Average	Crucible Component of Student Outcome
(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	70%	84%	Averages of the design component (architectural, structural, environmental, geotechnical) sustainability, and scheduling sections in the Design-Build competition
(3) an ability to communicate effectively with a range of audiences	70%	91%	Average scores from writing and presentation components in Design-Build competition
(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	70%	95%	Average of participation grades of the Design-Build competition as computed using the Team Leaders' grade and Faculty input

adjustments through its 15 year history in order to continually refresh and improve the program, two of which are discussed here. First, the department has varied how much access students could have to faculty members. At times, faculty were only available to answer questions through a strict RFI process, but this dissuaded students from getting help at times when they likely needed it. At other times, faculty were made readily available throughout the Crucible timeline, but this resulted in a strain on certain faculty members. The department ultimately settled on a compromise measure by requiring each team to consult for 15 minutes with one faculty member from each of the four sub-disciplines. Any additional questions about process or deliverables were still answered through written RFIs. This approach has improved the quality of student products while keeping time requirements for certain faculty to a reasonable limit.

A second notable change to the Crucible has been to the timeline. Originally, the competition was more closely modelled on the ASC competition timeline where students were given a problem set and asked to submit final products within 24 hours. However, the faculty noticed the challenge of coordinating a team as large as 15 people in that timeline, and started providing the problem a week in advance. While, the competition still has an intense 24-48 conclusion, faculty have noticed the quality of the work has improved with the extra preparation time.

## Summary

This paper presents a novel approach to conducting a capstone culminating event, by modelling it off of an industry-sponsored design-build competition. The event also provides additional leadership experience to 12 students each year prior to graduation. Finally, it serves as

one of two intense, high impact events which makeup the cornerstone and the capstone of an undergraduate civil engineering curriculum.

While service academies are unique in their purpose, structure, and traditions, the competition event described above could be readily adapted to any university. Every other team competing at ASC is from a civilian university, so the structure is not uniquely military. Additionally, nearly all of the projects used in the Crucible are designed and constructed by civilian firms, and a university partnering with its local industry or advisory board could find sponsors with relevant projects for their program.

Additionally, the event has been modified to fit in a civil engineering program by adding elements of geotechnical, environmental, and structural design elements. Other universities could easily incorporate additional civil engineering sub-disciplines, or they could adapt the competition for an architecture or construction management program. Furthermore, The Crucible provides a culminating experience conducted primarily in a one week timeframe without adding a separate 3-hour (or 6-hour) course, which could prove useful to other programs with constrained curriculums.

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