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Capstone Projects in Virginia Civil Engineering Programs: A Comprehensive Review of Practices and an assessment of Virginia Military Institute's Outcomes

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Abstract

Capstone projects serve as a vital bridge between academic theory and real-world application, equipping students with the skills necessary for professional success. Each university implements capstone projects in Civil Engineering (CE) using different styles, types of projects, and lengths of their capstone course. A survey of CE programs in Virginia was performed to gather information on Capstone courses. In addition to comparing CE programs across Virginia, this paper examines the capstone course at Virginia Military Institute (VMI), an institution that blends rigorous academic instruction with a military framework. The paper explores VMI's capstone projects' historical development and significance, highlighting how the military structure uniquely shapes their design and implementation. This study investigates the academic and career impacts of these projects, drawing on feedback from students and faculty. Additionally, it identifies opportunities for improvement, including fostering interdisciplinary collaboration, enhancing partnerships with industry, and refining assessment criteria. Finally, the role of continuous improvement mechanisms, such as ABET accreditation, are assessed to ensure the ongoing relevance and effectiveness of VMI's capstone programs. This research aims to provide insights into how capstone courses at VMI can continue to evolve, offering students a more comprehensive and integrative learning experience.

Keywords

capstone; civil engineering; continuous improvement

Introduction

Laying the capstone traditionally marks the final step in constructing a structure. Similarly, the Capstone experience marks the final step for undergraduate engineering majors before graduation. The Capstone experience is meant to build upon prior coursework and provide an overarching design opportunity; however, the details of this experience may vary with respect to timeline, structure, and project type. This paper examines the evolution of the Capstone course in the Civil and Environmental Engineering (CE) Department at Virginia Military Institute (VMI) since the late 1970s to highlight how Capstone has changed to meet new accreditation standards and to address new faculty hires. In addition to the historical information, current Capstone instructors and alumni were surveyed, and their experience is summarized herein. To round out the paper, Capstone experiences at ABET-accredited civil engineering (CE) programs in Virginia are also compared to address the current state of Capstones in the region.

The 2024-2025 ABET [1] Criterion 5: Curriculum requires "a culminating major engineering design experience." This culminating experience is often achieved through a Capstone course; alternatively, it may be embedded within a required course. The Capstone experience may be an opportunity to assess Student Outcomes as defined by ABET [1] Criterion 3, such as those related to communication, teamwork, and producing design solutions. It can also be an opportunity

to connect with the industry, which is a significant focus of some engineering programs [2], [3]. Through a regular assessment of Capstone experiences, avenues for continuous improvement can be identified to provide a meaningful experience through the best learning opportunity for students.

Historic evolution and current Capstone practices at Virginia Military Institute

The study provides valuable insights into the CE Capstone course at VMI, highlighting its evolution, impact on students, and areas for improvement. The current Capstone course at VMI is a 3-credit course offered during the spring semester of a student's final year (typically). It is designed to provide a comprehensive, hands-on design experience across multiple sub-disciplines of CE. In this course, students are assigned a hypothetical project and tasked with developing a unique solution as part of a team. The course encourages collaboration, with each student contributing to a series of graded tasks, culminating in a final design report at the end of the semester.

The VMI CE Capstone project centers around a hypothetical Naval Facilities Engineering Systems Command (NAVFAC) assignment to design a new facility for the U.S. Marine Corps (USMC) Company E, 4th Reconnaissance Battalion (RECON). The objective is to create a space that meets the needs of 100 part-time Reserve personnel and 12 full-time staff members. The new structure must support supply, storage, and training activities while promoting the mission of the 4th RECON Battalion. Additionally, the project emphasizes sustainability, aiming to meet LEED certification requirements and minimize environmental impact on the surrounding community of Lexington, Virginia. The final report for this project incorporates key CE disciplines, including site drainage and erosion control, grading and landscaping, parking and access roads, site utilities, and the design of foundations and steel structures. Throughout the semester, each team is required to submit a series of deliverables, including a Statement of Work (SOW), a Basis of Design Report (BODR), an outline of required specifications, schematic designs, and ultimately, the final design report, which includes detailed drawings and an estimation of probable costs.

A thorough review of the course catalog, coupled with insights from former students and past and current instructors, reveals that the capstone course has significantly evolved to keep pace with emerging trends in CE. Historically, the capstone was centered around a group or independent research/design project in collaboration with a faculty member. However, in response to the need for better management of faculty-student ratios, to meet ABET accreditation standards, and to address the industry's changing landscape, the CE department introduced its current capstone format around 2008.

Initially, the course was structured around a single project template—a request for proposal (RFP). Over time, it has incorporated cutting-edge tools and practices, including Geographic Information Systems (GIS), LEED certification, and sustainability features like solar panels, reflecting the growing emphasis on environmentally conscious engineering solutions. To better understand the academic and professional impacts of these projects, two surveys were conducted among instructors and alums to evaluate the outcomes and identify potential areas for improvement in the capstone experience.

Current and former capstone instructors' responses:

Instructor responses indicated a consensus that the course effectively prepares students for both military and civilian engineering careers. The Capstone project includes military contexts like designing a Marine Corps training facility and emphasizes teamwork, communication, and problem-solving—skills essential in both professional practice and the military. While students acknowledge the course's high workload, especially near graduation, graduates reported that the Capstone closely mirrors the collaborative, multidisciplinary work they encounter in the field. A key strength of the project is a consistent core structure integrating multiple engineering disciplines.

Instructors noted that student feedback about the Capstone course highlighted both the course's challenges and its value. While students sometimes felt overwhelmed by the project's scope, especially in the final semester, many noted that the Capstone provided essential real-world experience. However, there were concerns about uneven workloads among team members, with some suggesting more structured peer evaluations to improve team dynamics.

For continuous improvement, the survey highlighted the importance of integrating more technology, such as Building Information Modeling (BIM) and AI design tools, into the course. Some survey responses also suggested a two-semester sequence to allow more time for the design process and client feedback. Instructors recommended enhancing project management and collaboration tools to reflect industry practices better. Overall, the Capstone course was praised for bridging the gap between academic training and professional practice, with most instructors agreeing that it successfully prepares students for their careers despite its challenges.

Alumni Responses:

The survey, gathering input from VMI CE graduates from 1977 to 2013, highlighted diverse capstone project experiences, including individual research, independent studies, and real-world design and research-based initiatives. Respondents consistently emphasized the need for a stronger focus on practical problem-solving with suggestions to incorporate cutting-edge technologies like BIM and AI. While design, teamwork, and problem-solving are integral to the current capstone structure, the survey responses suggest a need for more explicit instruction on "how to" approach these skills. Currently, students gain these abilities through their capstone project completion and faculty feedback, but structured guidance on interdisciplinary collaboration, client interaction, and modern methodologies is limited. A popular recommendation was to make the capstone a two-semester course—feasibility and conceptual design in the fall, final design in the spring—and to allow independent studies and honors theses to fulfill capstone requirements. There was also a call for more industry collaboration, with suggestions to partner with engineering firms on real-world projects.

Most graduates found the Capstone course effective at integrating academic theory with real-world application, enhancing technical skills, and developing critical thinking. There was less confidence, however, in its ability to foster interdisciplinary and collaborative skills. Faculty support was widely acknowledged, but industry support was more moderate, with some noting a lack of

industry engagement. Overall, the capstone format was seen as sufficient. However, deeper industry involvement and more complex problem-solving were identified as areas for improvement to better prepare students for the evolving CE field.

Survey analysis highlighted opportunities to enhance VMI's CE Capstone through interdisciplinary collaboration and advanced technology integration. Partnerships with biology, chemistry, and computer science departments could address sustainability, data analysis, and AI-driven design, while business and psychology could contribute to project management and human factors. Industry and alums involvement would provide mentorship and real-world context. Integrating tools like Building Information Modeling (BIM) and Artificial Intelligence (AI) within the Capstone is crucial. BIM can be used for design visualization, project management, and collaboration, while AI can be useful for predictive analytics and intelligent decision-making. Research also supports these technologies' role in enhancing technical skills, critical thinking, and modern construction management [4], [5], [6].

Structure of Capstone Projects in ABET-accredited CE Programs in Virginia

To make further recommendations to align the Capstone practice at VMI with the rest of the CE programs in Virginia, ABET-accredited CE programs in Virginia were researched using university websites, catalogs, and personal interviews. Building upon the responses gleaned from Capstone instructors and alums from VMI, information gathered included how many semesters the Capstone experience spans, how many Capstone courses are offered, whether students complete different Capstone projects or the same project, and if students meet with clients outside the university (Table 1). Additionally, basic information about each university in Virginia was included to help with the comparison. The search was restricted to ABET-accredited programs since ABET Criterion 5 is often met with the inclusion of a Capstone (or culminating design) project, and non-accredited programs would not be required to meet the same criteria.

Looking at the six accredited CE programs in Virginia (Table 1), half of the programs offer a Capstone experience spanning two semesters of the student's final year with total Capstone credits ranging from four to six. Many universities also offer a required professional development course in addition to their capstone experience. Any additional professional development courses are not included in the capstone semester and credit counts of Table 1, even though they may cover some of the same information and skills covered in a capstone course. The seventh university in Table 1, James Madison University (JMU), is an ABET-accredited General Engineering program. However, it was included in this study because it offers a CE concentration within the degree. JMU's Capstone is like the three other CE department Capstone projects in Virginia, requiring only one semester of the Capstone course, although the course is preceded by two semesters of "Engineering Project Design."

Most universities offer the same Capstone course for their entire CE department, except for one (Virginia Tech). Virginia Tech also had the most CE students graduate last year, far outnumbering any other program in Virginia. While most CE majors take the same capstone course at their university, most (five out of seven) universities offer their students different Capstone projects to

complete within the course. The various projects are often based on a student's discipline of interest (Virginia Tech, University of Virginia, and JMU). In contrast, at other institutions, projects incorporate multiple disciplines into one project (VMI and Liberty University).

Many of the alums and instructors surveyed at VMI indicated that more interactions with clients outside of the university would improve the Capstone project at VMI. When researching other universities in Virginia, four universities specifically stated that they work with outside clients; two universities did not state that their students worked with outside clients, while VMI is the only known university that did not work with outside clients. Overall, working with outside clients seems to benefit the student's experience [3]. However, the faculty role in coordinating this is significant and often has to be completed in the summer before the Capstone course [7] (or fall if the Capstone is only offered in the spring semester).

Overall, the design courses appear to have many similarities. The course descriptions for each university's design course are included in Table 2 and Appendix B. Examining the capstone courses for all universities, except for Virginia Tech, the most common words include design, engineers, and project, none surprising for a culminating design course. However, a few of the less used words are surprising, such as teams, report, and cost, although the lack of occurrence may be due to the many synonyms such as peers/group, report, and economics. A word cloud is included in Figure 1 to visualize the catalog course description terms. The more often a word is used in a description, the larger it appears in the word cloud. Virginia Tech was excluded from the word cloud since it offers many Capstone courses for its CE cohort, but the description of each course is included in Appendix B.

Table 1: Summary of Capstone course offerings at Virginia Universities with ABET-accredited programs [8]

University	*# B.S. CE degrees conferred 2022-2023 [8]*	*# of semesters in Capstone course (fall – FL, spring, SP)*	*# credits*	*same Capstone course for entire department?*	*same Capstone project for the entire department?*	*project meetings with client outside the University?*	*ABET-Accredited Program? [16]*	*Notes*
Virginia Tech [9]	242	1 (FL or SP)	3-4	no	no	course dependent	yes - CE	one "design project course" is offered in each subject area (7 possible areas – See Appendix)
University of Virginia [10]	36	2 (FL and SP)	5	yes	no	project dependent	yes - CE	
George Mason University [11]	80	2 (FL and SP)	4-6	yes	no	?	yes - CE	
Old Dominion University [12]	34	1 (SP)	3	yes	?	?	yes - CE	Grade of C or better required
Virginia Military Institute [13]	42	1 (SP)	3	yes	yes	no	yes - CE	
Liberty University [7], [14]	7	2 (FL and SP)	6	yes	no	yes	yes - CE	Each project should contain at least 3 CE sub-discipline component.
James Madison University [15]	66 (General Engr)	1 (SP)	2	yes	no	yes	yes - General Engineering	include a CE concentration in their program

Table 2: Capstone course descriptions at universities in Virginia.

University	*Course Description*
Virginia Tech	See Appendix
University of Virginia [10]	First Course: "Team-based project course focusing on a design in a sub-discipline of civil and environmental engineering. Student participants will develop professional practice skills, such as project scoping, scheduling, cost-estimation, and appropriate technical communication, and visual representation of designs. Projects will continue in CE4992." Second Course: "This course will broaden a student's exposure to professional practice issues, including project planning and management, cost engineering, and leadership. The major focus of the course will be providing practical civil engineering design experience. Projects will address appropriate constraints and engineering standards"
George Mason University [11]	First Course: "This course is the first course in a two-course sequence in the Civil Engineering Program. Students will be working on civil engineering projects, integrate their acquired fundamental engineering knowledge and incorporate input from practitioner engineers from industry." Second Course: "Students form multidisciplinary design teams, select real-world civil engineering projects, develop preliminary design solutions, and prepare a draft technical report. Students will learn necessary computer-aided design software and become familiar with engineering codes and standards."
Old Dominion University [12]	"Group design project of civil engineering systems requiring synthesis, data gathering, preliminary investigation, master planning, conceptual designs, layouts, support studies, cost estimates and report writing. Emphasis will be on alternatives, constraints, economics, ethics and professional practice, business and project management, public policy and leadership"
Virginia Military Institute [13]	"Application of civil engineering principles to comprehensive engineering problems. Planning and design of realistic projects."
Liberty University [14]	"The first course in the design sequence of formal design courses that emphasizes the design process. Student teams carry a project from inception to completion to satisfy the need of a client. In addition to technical design, factors such as safety, economics, and ethical and societal implications are considered." "The second course in the design sequence where the student is exposed to engineering design and development. Design process culminates in prototype development, gathering performance data and presenting a final design briefing to peers and department faculty."
James Madison University [15]	"The engineering project experience entails a process of devising a system, component, or process to meet the desired needs and specifications within constraints. This course builds on engineering project analysis, improvement and evaluation to expand into engineering project justification, delivery, and documentation"

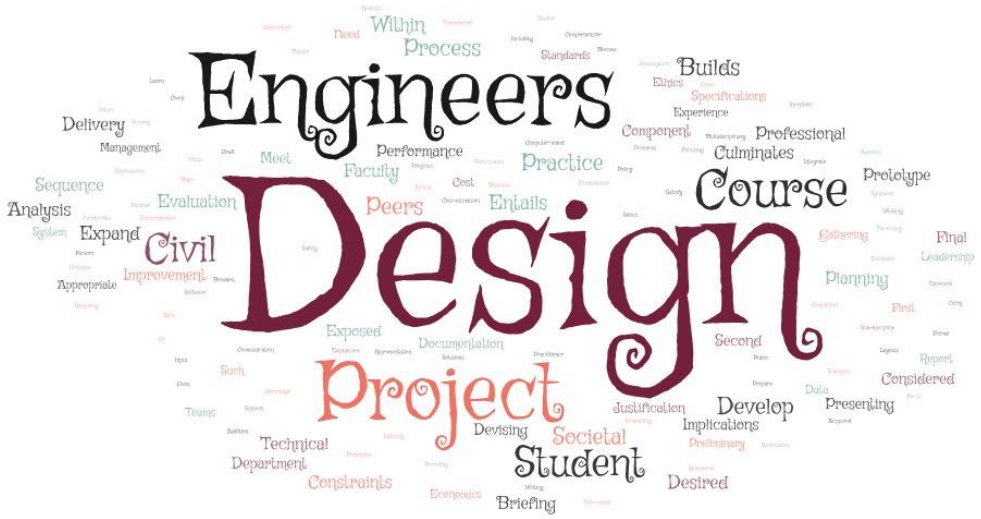

Figure 1: Word Cloud of the Capstone course descriptions. The larger the word, the more often it is used in a capstone course description. Created using wordart.com.

Conclusion

In accordance with ABET criteria and to accommodate growing expectations of faculty at the university, capstone projects have evolved at VMI from individual research projects to team research projects to the team design project that is in place today. Both alumni of the CE program and instructors of the Capstone course agree that incorporating partnerships with outside clients would benefit the Capstone course at VMI, as well as incorporating more technology into the experience and adjusting the oversight of the team allocation of the workload. Looking at other Virginia universities, the majority of them include outside clients in their Capstone experiences to some extent. Only 50% of CE programs in Virginia require a two-semester Capstone course, although some separate a professionalism course from the Capstone experience. Additionally, the consensus of the design aspect of the Virginia universities' Capstone courses aligns with the ABET criteria 5 of including a "culminating design experience" into the curriculum while including their own spin on the project to include multidisciplinary work, feasibility studies, and teamwork. Overall, this paper showcases the widespread implementation of industry partners in Capstone projects and the split in Virginia regarding one and two-semester Capstone projects, both of which should be strongly considered for implementation at VMI.

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Appendix A – Survey Questions asked of Instructors and Alumni

<u>Questions for the VMI alum survey:</u>

1. Which year did you graduate from VMI? -Open-ended.
2. What type of capstone project did you complete?
    - Design-based
    - Research-based
    - Practical (real-world problem-solving)
    - Other (please specify)
3. How effective was the capstone project at doing each of the following:

Integrating academic theory with real-world application	Very effective	Sufficiently effective	Not effective	Not sure
Enhancing technical knowledge and skills				
Helping you develop critical thinking skills				
Helping you develop problem-solving skills				
Enhancing your ability to work collaboratively with peers				
Enhancing your ability to collaboratively work across disciplines				
Preparing you for a career in Civil Engineering and the evolving needs of this field				
Influenced your future career path				

8. To what extent to you agree with each of the following statements:

You received support from faculty during your Capstone.	Not at all	A little	A moderate amount	A lot	A great deal
You received support from industry professionals during your Capstone.					
You believe the capstone format you had was sufficient.					

4. What additional skills or experiences do you think should be included in the capstone course to better prepare future students for their careers?
    - More emphasis on soft skills (communication, leadership)
    - Greater focus on sustainability and ethical decision-making
    - More exposure to cutting-edge technologies (e.g., BIM, AI, etc.)

- Other (please specify)

5. In your opinion, how could the VMI Civil Engineering Capstone course be improved overall? -Open ended.

Questions for former/current VMI Civil Engineering instructors Teaching the Capstone Course

1. How many years have you been involved in teaching the Civil Engineering Capstone course at VMI?
2. Please describe the current capstone course at VMI and how, if at all, the military environment shapes its goals, design, and execution.
3. In your opinion, how well does the VMI capstone prepare students for professional practice in Civil Engineering, and what key skills or competencies do students develop most effectively?
4. How has the capstone course at VMI evolved over the years, particularly in terms of its structure, objectives, and project scope?
5. What student feedback have you received on the capstone course, and how do you assess its success in bridging academic training with real-world challenges?
6. What mechanisms are in place for continuous improvement of the VMI capstone course, and how do factors like student feedback, industry input (if any), and ABET accreditation influence its design and assessment?
7. What key improvements would you suggest for the VMI capstone course so that the emerging trends in Civil Engineering education can be integrated to better prepare students for the future over the next 5-10 years?
8. What is your overall experience with teaching the capstone course at VMI?

Appendix B – Capstone Course Options for Virginia Tech

Subject Area	*Course*	*Course Description*
Construction Engineering and Management	Estimating, Production, and Cost Engineering	"Interpretation of plans and specifications, preparation of construction estimates, and cost control. Methods analysis, resource requirements, and resource costs in building systems, including system components, and in large-scale civil engineering works such as highways, bridges, and hydraulic structures."
Structural Engineering and Materials	Design of Steel Structures 1	"Behavior and design of structural steel members and steel-frame buildings, including simple and fixed connections. AISC specifications; elastic theory. Design members to resist tension, compression, bending, torsion; plate girders, composite beams."
Environmental Engineering	Water and Wastewater Treatment Design	"Design of municipal water and wastewater treatment plants. Emphasis on characterization of water and wastewater and physical, chemical, and biological treatment methods. Sludge processing advanced treatment methods and treatment plant hydraulics are considered."
Materials	Pavement Design	"Principles underlying methods for the design of various elements of flexible and rigid pavements for highways and airports; climate and traffic effects; pavement management systems."
Land Development	Land Development Design	"Overview of land development projects including construction practices, legal issues, and government policies. Feasibility study, engineering evaluation. Grading and roadway design, layout design of lots, buildings, streets, sewers, and stormwater control. Interactive graphics and automated drafting."
Geotechnical Engineering	Design of Earth Structures	"Application of geotechnical engineering principles in the design and construction of earth structures. Subsurface models, shear strength of soil, slope stability, earth fills, earth retention, ground improvement, sustainability considerations, geotechnical reporting. Team-based design project."
Water Resources Engineering	Hydraulic Structures	"Hydraulic analysis and design of engineering structures for water control, including reservoirs, dams, spillways, spilling basins, drainage structures, and hydraulic models."
Transportation Engineering	Geometric Design of Highways	"Functional design of highways; curves, intersections, interchanges, drainage, and other features involved in highway safety and traffic efficiency."