

Recipes for capstone design courses: a review of key considerations in the capstone course landscape (Work in progress)

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Abstract

The capstone design course is a core pre-graduation requirement in today's engineering degree, expected by accreditation bodies, employers and students alike. This monolithic requirement hides a wide variety of capstone types, however, in terms of team size, disciplinary mix, course duration and intensity, stakeholder engagements, funding, grading emphasis, and expected design and project management approaches, amongst others.

Having been involved in teaching a variety of capstones over the past decade, the authors propose a capstone classification in this paper, to make it easier to compare capstone courses. The goal of this classification is to help improve and connect capstones, and make it easier to compare best practices in different capstone course types. This paper builds upon previous work that proposed a standardized way to classify capstone courses, by providing some text and context behind the classification, with the goal of testing out these capstone classification descriptions with conference attendees and other stakeholders. With confirmation or adjustment based on conference feedback, this capstone classification will be available for use by the capstone community, which will facilitate exchange between capstone practitioners, and support future Scholarship of Teaching and Learning (SoTL) work into capstones by providing a common language to compare these complex courses.

Introduction

Engineering capstone design courses are a critical component of modern engineering education, serving as a bridge between academic learning and professional practice [1]. These courses provide a culminating experience where students apply theoretical knowledge and technical skills to address real-world engineering challenges. By engaging in practical, hands-on projects, students simulate professional engineering practice and gain exposure to industry expectations. Moreover, capstone courses are instrumental in fostering essential professional skills such as teamwork, communication, and project management [2], [3].

These courses also meet accreditation requirements, such as those set by ABET (or CEAB in Canada or ENAEE in Europe, for example), which mandate a major design experience integrating considerations like sustainability, manufacturability, and regulatory compliance [4], [5]. Through these projects, students demonstrate their ability to design systems, components, or processes that meet specified needs under various constraints [6].

The expectations for capstone courses encompass multiple facets of professional engineering practice. These courses emphasize the application of engineering knowledge in complex, open-ended problem-solving scenarios. Students often work collaboratively in teams, reflecting the collaborative nature of modern engineering, and produce tangible deliverables such as prototypes or detailed project reports. Capstone courses also require students to consider real-world factors such as economic constraints, environmental impacts, and societal needs [7]. Industry or

community engagement is a common feature, with external clients providing practical challenges and broadening the scope of learning [2], [8]. Furthermore, these courses demand iterative design processes, critical reflection, and comprehensive assessments that evaluate both the final product and the underlying methodologies [9].

The structure and implementation of capstone courses vary widely among institutions, and even within the same institution [10], [11], [12], reflecting diverse educational goals and resources. Some courses span one semester, while others extend over two semesters, incorporating both project-based and lecture components. Project sources also differ, ranging from faculty research and industry partnerships to design competitions. Team composition and formation strategies vary, with some institutions allowing self-selection and others assigning teams systematically to enhance dynamics. The focus of capstone projects may emphasize technical proficiency, professional skills, or a combination of both. Additionally, some courses concentrate solely on the design process, while others require the development of functional prototypes.

While these courses vary widely in structure and focus, their core purpose remains consistent: to prepare engineering graduates for the demands of the profession. Addressing the inherent challenges of capstone courses through thoughtful design, implementation, and assessment will ensure their ongoing relevance and effectiveness in engineering education.

To better understand and compare these diverse capstone courses, this paper proposes a standardized classification system to facilitate the exchange of best practices among capstone practitioners. This work builds upon previous efforts to categorize capstone courses, aiming to provide additional context and nuance to the classification scheme.

To test this new classification, it presents a questionnaire that will be used to assess this classification and how well it fits to the attendees' capstones. The questionnaire will capture nominally available information on capstone courses, nominally avoiding any personal information. A subset of the questionnaires' elements, usually available publicly, will be shared in a public database (for any participants who agree to sharing the information), to support building a broad community of practice of capstone instructors.

This paper therefore has four goals:

- To propose a set of categories with which to classify capstone courses
- To provide the outline of a proposed questionnaire for capstone faculty, to assess the capstone landscape
- To provide a public catalogue of capstone courses and contacts for anyone open to sharing, to support building a community of practice around capstone courses and
- To present the ways in which the proposed data collection can be used by practitioners and researchers to improve the understanding and implementation of capstones in future

Capstone classification and questionnaire

Building upon [13], this paper proposes the categories of capstone courses illustrated in Figures 1-4 below. These categories are built on the literature reviewed in [13] as well as feedback since

presenting that preliminary categorization. The categorization of capstones is divided into four sections, namely:

- the format of the course,
- the team involved in delivering it,
- the content of any scheduled class time and
- the assessment and feedback used in the course.

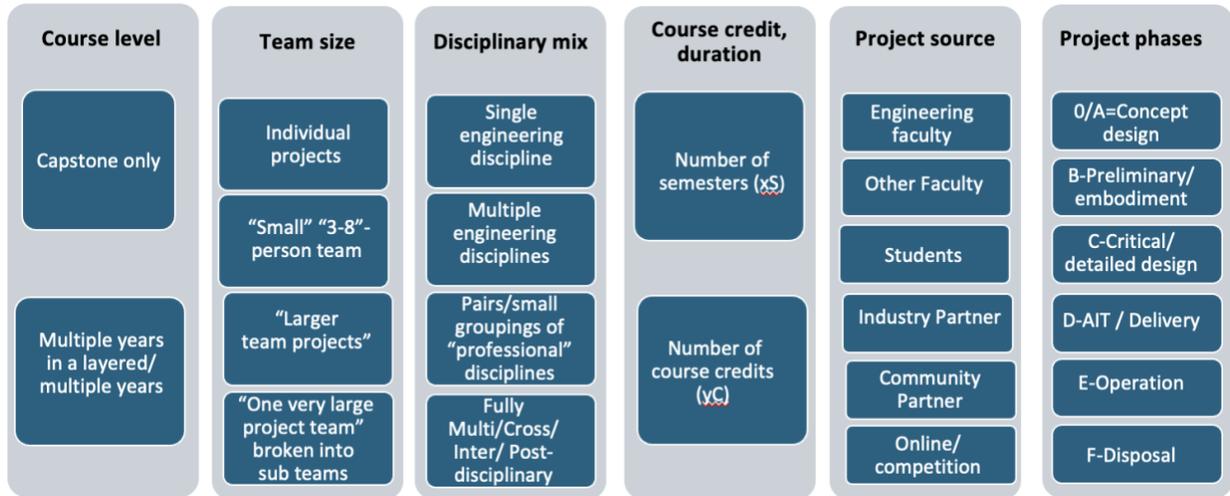


Figure 1: Options for capstone course formats

The capstone format section (Figure 1) probes the form and format of the capstone courses currently being offered, in terms of the mix of students (by year and discipline), student team size, credit available to students and intensity and duration of the capstone, source of capstone projects and which design phases are covered in the course. These facets of capstones define the key structure of the courses, within which the other elements sit.

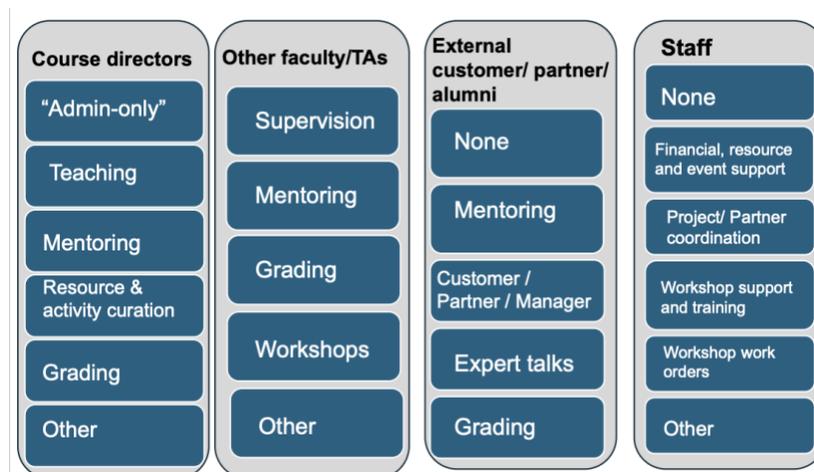


Figure 2: Make-up of capstone delivery team

Capstone team (Figure 2) looks at the faculty, and any TA and technical and administrative staff roles within the capstone course, as well as the roles of industry or other partners or external

experts. These facets capture the types of activity and support needed in the capstone landscape to run this specific type of course.

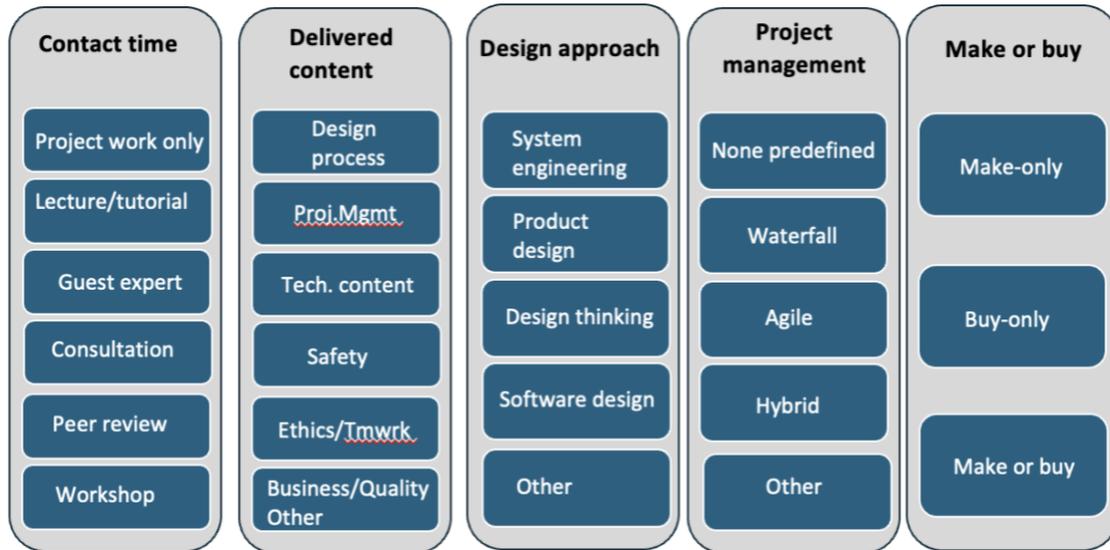


Figure 3: Scheduled capstone activities and approaches

The capstone content section (Figure 3) looks at the activities that happen during any scheduled capstone class time, and the format in which they are delivered. It also looks at two key components of all capstone courses - the design approaches used and the project management approaches applied, and who selects these approaches. These facets capture the class dynamics and key project approaches used during the projects undertaken by students.

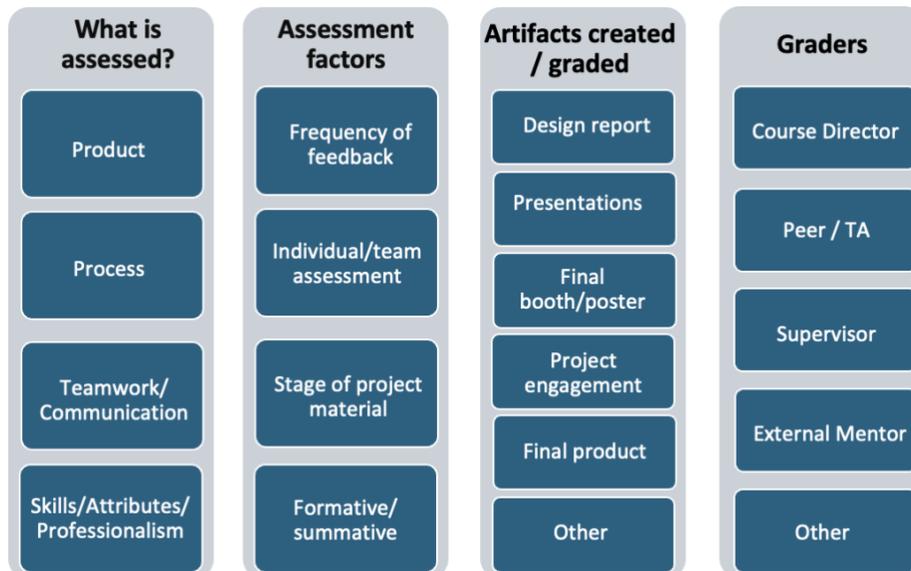


Figure 4: Categories of capstone assessment choices

Capstone assessment (Figure 4) looks at what artifacts students are expected to create during their capstone courses, and what is assessed. It looks at when ungraded formative, graded

formative and graded summative feedback are given, if at all. It also looks at the degree of team-based vs. individual grading, and whether team-based grades are differentiated within the teams. Finally, it looks at who in the capstone team is responsible for assigning grades. These facets help understand what is scaffolded within our capstone spaces and what contributes to grades.

The related questionnaire asks participants to identify their capstone courses within these categories. The questionnaire has four sections based on the categories above, and adds a final fifth section, which provides an opportunity for those completing it to give feedback on the questionnaire itself - how easily the questions map to the types of capstone in our institutions, and what may be missing, irrelevant, surprising or exciting about the questions asked, if anything. This can help future iterations of the questionnaire and can also inform the capstone categories identified in this work.

The questionnaire will be sent out to faculty across North America over the coming months and shared through engineering education forums. The questionnaire can be found here:

<https://forms.gle/Pt4dhPwQ1Fpcp6ix6>.

Public catalogue of capstone courses

In addition to the core questions relating to capstone categories, participants in the questionnaire will be invited to share public information relating to their capstone courses in a database that will be made available publicly through a capstone website, as information can be verified. The information to be shared in the public database will consist of:

- The institution and course name
- A contact name and email for the course
- The nominal start and end date of the course
- The nominal year(s) of capstone students, and team sizes and disciplinary mixes
- The project sources (student proposal/industry/faculty etc.)
- The design and project management approaches used in the course and who selects these

This catalogue of capstone courses is intended to facilitate communication between faculty and staff engaged in this form of instruction, which presents unique challenges and opportunities in the undergraduate engineering education landscape. The elements have also been specifically selected to facilitate the possibility of cross-institutional capstone projects for any colleagues interested in exploring these possibilities. The contact information is intended to support development of specific capstone-related communities of practice across engineering faculties.

Goals of capstone data gathering

The questionnaire presented in this paper is intended to support a wide range of stakeholders in the capstone space. The gathered data will be analyzed and developed into a paper to inform the community of the results. The key stakeholders who will benefit from this work include:

- Capstone course instructors and staff
- Engineering curriculum committees and
- Engineering education researchers

The questionnaire is intended to give an opportunity for capstone instructors to make visible the design choices they may or may not have explicitly made in the design of their capstones, and understand the landscape of engineering capstone courses and where their course sits within this landscape. For faculty who are considering modifications to their courses, the results of this questionnaire will allow them to make more informed choices based on common practices across the sector, either to align to others or to differentiate their offering from others. Similarly, capstone staff will gain insights into best practices related to their roles and activities, helping improve course implementation and delivery.

For curriculum committees, a common concern related to capstone courses relates to their important role in addressing specific graduate attributes within undergraduate engineering programs. By understanding the landscape of capstone course offerings, it may be easier for curriculum committees to approve more innovative course offerings by finding other novel offerings within the landscape. For committees looking to implement best practices, common practices across this type of course will be more easily identifiable. Curriculum committees looking at modifying their capstone courses to better support their students may also find the capstone landscape provides a range of existing capstone structures in other institutions from which to be inspired to adjust their own offering.

There is quite extensive literature in the scholarship of teaching and learning (SoTL) on the benefits of capstone courses, and the nature of capstone course implementation, delivery and assessment. Because of the wide range of classes that fall into the category of capstone courses eligible for engineering students, there have not been many studies of the landscape of capstone courses, nor comparative studies of effective capstone practices for specific types of capstone course, however. Clearly, for example, there are best practices for supporting students in projects running agile project management that would not be relevant to waterfall-based capstone courses. The questionnaire data will inform what are common practices in capstones, and what unique capstone offerings are available, as well as identifying possible gaps in the landscape of capstone course offerings that may need to be filled (for example the absence of capstone courses considering the disposal phase of engineering design). It will allow SoTL scholars to compare similar capstone course types when looking for effective and best practices in the capstone classroom.

Conclusion

This paper presents a new classification of engineering capstone courses and introduces a questionnaire to assess where existing capstone courses fall within this classification. It proposes using the gathered data to build a public catalogue of capstone courses, to facilitate exchanges across institutions between staff and faculty who play in this important and challenging part of undergraduate engineering curricula. It also proposes to gather a wide ranging set of information regarding capstone course structure, delivery teams, course content and assessment, to help practitioners, those developing and managing engineering curricula, and engineering education researchers alike, to understand the full landscape of capstone courses and where their own offerings fit into this landscape.

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