Civil Engineering Capstone Inventory: Standards of Practice & The ASCE Body of Knowledge

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Abstract

Civil engineering curriculums culminate in capstone or senior design experiences, often considered a critical component to the academic training of the undergraduate population. Entities such as ASCE and ABET, along with other accrediting programs, university standards, departmental and college expectations present broad standards and requirements for capstone courses. The ASCE Body of Knowledge (BOK) recently identified capstone experiences as supporting the developing abilities for young civil engineers entering the profession in five distinct outcome areas. While some similarities exist across the U.S. and Canadian undergraduate programs, many elements of the courses are still quite diverse allowing for very unique opportunities for students. Capstone course instructors are faced with the challenge of accommodating the expectations of governing bodies both internal and external to the home institution while creating a valuable learning experience, often dared to be dynamic or innovative to enhance the specific institute's missions and strategic plans. While the variation is supported as the mechanism for students to choose the most appropriate program catered to their interests and ambitions, faculty members may struggle to identify the suitable expectations to define their program as successful. A survey of "biographical" information for civil engineering programs has been conducted to obtain data to capture the state of the art of civil engineering senior design course experiences at U.S. and Canadian institutes. Additionally, ASCE's most recent Body of Knowledge identifies (5) BOK "Outcomes" associated directly with capstone experiences and the survey results identify the adaptability of current senior design courses to capture demonstrated abilities in these outcomes. Through capturing the standards of practice for a good number of programs and mapping those programs to the ASCE BOK outcomes, a baseline for defining a successful program should become evident.

Introduction

The Capstone or Senior Design experience is a culminating project opportunity for students to showcase the engineering skillset obtained throughout their academic training experience, yet a universal understanding of the standard of practice has not been inventoried specifically within Civil and Environmental Engineering (CEE). With such critical relevance, the course experience is often used to assess student knowledge through programs such as ABET's program reviews, regional accreditation programs, and internal university departmental reviews as one opportunity to evaluate the ability of students to apply the engineering fundamentals to a complete design problem or project. Within the civil engineering field, and related programs in construction engineering, construction management, environmental engineering, and architectural engineering, university departments develop the capstone experience independently and have not intentionally aligned experiences across programs. This latitude allows programs to develop curriculum and student experiences specific to the university and departmental missions, but can be intimidating to faculty responsible for designing the critical experience with few universal requirements. An inventory of common practices across the country to identify similar and dissimilar traits is valuable to faculty designing new experiences, aligned to new expectations for civil engineers of today, mindful of the technology resources available to students at most institutions, and with the ultimate value of ensuring the experience is comparable to programs with similar program missions. Additionally, the opportunity to inventory current standards of practice in capstone experiences is timely with the most recent release of ASCE's Body of Knowledge (BOK) which directly references the capstone experience as an integral part of the traditional pathway to attain basic skills in (5) "outcomes". The narrative developed herein presents a brief literature review for historic cataloguing of past capstone inventories, describes the design of a survey inventorying civil engineering and related field senior design courses across the country, summarizes the survey responses received, and presents findings on the preparedness of programs' ability to formally assess learning aligned with ASCE's BOK outcomes.

Literature Review

Senior Design or "Capstone" classes are a culminating academic experience for students, typically, at the end of their academic program. These courses prepare students for work following graduation and are designed to meet the Accreditation Board for Engineering and Technology (ABET) requirement of a culminating major engineering design experience (ABET, 2019). Capstone design courses are also considered an "high impact" instructional practice (AACU, 2008).

There are many characteristics of a capstone design class that can vary substantially from institution to institution including team characteristics (i.e. size, organization, multidisciplinary), length of the course (one semester or multiple semesters), type of projects, and integration with industry partners. While there are many student level surveys of senior capstone experiences (G. Padmanabhan, 2018; Saleh, 2011; Brouwer, et. al, 2011; Aidoo et. al, 2013; Nelson et. al, 2014; Shah et. al, 2019 are a few examples), there have been only a handful of institution level surveys of senior capstone classes and experiences.

There have been initiatives to survey ABET accredited institutions to document the various ways in which these institutions implement their Capstones. A comprehensive survey of ABET accredited institutions was performed by a group from Brigham Young University in 1994 (Todd et al, 1995). This survey asked questions intended to characterize engineering capstone classes in North America and found that there is a wide variety of capstone experiences. Team size, lecture driven or project driven, funding, industry involvement, deliverables, and class length were some of the characteristics investigated. However, the only data broken out for CEE Departments was that 7% reported participating in interdisciplinary or inter-departmental Capstone courses.

In 2004 and 2005, there were two follow up capstone surveys. The 2004 survey, by McKenzie et. al (2004) received results from 119 institutions about assessment practices. No Civil Engineering data was broken out in the results. The 2005 survey was completed by Howe and Wilbarger (Howe and Wilbarger, 2006). This survey focused on the diversity of course logistics, faculty involvement, project coordination, funding, and industry involvement. Consistent with the 1994 survey, the only data broken out for CEE Departments was that 9% reported as participating in interdisciplinary or inter-departmental Capstone courses. This survey was repeated in 2015 (Howe et al. 2017). The three surveys of ABET accredited programs do include Civil Engineering programs, but the surveys in 1994 and 2005 only break out a small amount of data related only to Civil Engineering. The 2015 capstone survey (Howe, et al, 2017) does break out more detailed information related directly to Civil Engineering. The Civil Engineering data include number of students per class, team size, faculty/student ratio, and number of projects per class.

Besides these decennial capstone surveys, there have been other capstone surveys conducted for programs not necessarily ABET accredited. The National Resource Center for the First-Year Experience has conducted surveys of institutions about their Senior Seminar/Capstone courses. This Center conducted surveys in 2000 (Henscheid, 2000), in 2012 (Padgett & Kilgo, 2012), and in 2016 (Young, et. al, 2017). It is unclear if the National Resource Center for the First-Year Experience surveys include any engineering programs at all, let alone Civil Engineering programs.

Discipline-specific capstone surveys have also been conducted, including a 2016 survey of Capstone projects in Statistics programs (Martonosi & William, 2016), Chemical Engineering Capstones (Silverstein, 2012), Biology Capstone Courses (Haave, 2015), and Architectural Engineering Capstones (Solnosky, 2019). In 2012, Fries, et. al. published a survey of Civil Engineering program to assess how these programs were meeting revised ABET criteria (Fries, el al., 2012), but this survey included very limited details regarding Capstone experiences.

While there have been surveys of Civil Engineering programs in general, there are not published institution-level capstone surveys of Civil Engineering capstone classes. There seems to be a gap in knowledge of Civil Engineering capstone classes across ABET accredited programs. This paper attempts to gain more detailed information about Civil Engineering Capstone classes.

Purpose

Capstone or senior design experiences are valuable in measuring many aspects of student learning and are often utilized by academic programs to document skillsets not only in technical competence, but also professional skills such as teamwork, communication, and applied critical thinking. While programs have the ability to generate an experience suited to the overall curriculum and objective specific to the program and institutional missions, standards of practice likely exist and some best practices could potentially inform design and re-design of the course experience as a component of continual program improvement. Ultimately, this inventory is intended to assist faculty in developing capstone experiences that are relevant, meaningful, and suitable to the skillset of undergraduate engineering students. The inventory may extend to opportunities for allocating resources to the course experience to ensure that the course matches comparable programs and students are provided the greatest opportunity to showcase their academic preparation.

ASCE's Body of Knowledge is a valuable resource for junior engineers to recognize the skills and training necessary to enter the civil engineering profession, yet the resource has not necessarily been adopted among civil engineering faculty in a deliberate way. The authors of the BOK specifically identify the senior design course as the likely opportunity for students to acquire knowledge in specific professional categories supporting full development into competent civil engineers. The BOK's language identifies the course as one component of the "typical pathway for fulfillment" for the Social Sciences, Critical Thinking and Problem Solving, Teamwork and Leadership, Professional Responsibilities, and Ethical Responsibilities. With these (5) outcomes specified, a need to inventory current practices is warranted. While many civil engineering senior design courses integrate lessons and activities that do include these aspects of the engineering process, not all programs use this specific course to formally teach or formally assess student learning in all of these categories. A survey of standard practices in these courses will provide data to assist faculty in ensuring their courses are mindful of ASCE's recommendation for junior engineer development, may encourage faculty to alter experiences to accommodate the variety of skillsets demonstrated in these diverse outcomes, and would likely improve the preparation of engineering students entering the profession. The survey may also assist engineering students in identifying an academic program aligned with the ASCE BOK's intention of guiding junior engineers towards professional status, ideally improving their transition from academics to practice as civil engineers.

A current survey of standards of practice today can be valuable in both identifying the standards of practice across the academic industry and in reporting the current status for integrating ASCE's BOK outcomes into formalized program assessment practices. Of specific interest are a series of metrics that capture the standard procedures in the course; these include: course demographics, resources available to the instructors and students, grading schemes and structures, team formulation, development of projects, partnerships with clients and mentors, and industrial involvement. Additionally, a survey of the preparedness of adoption or implementation of (5) "capstone" ASCE's BOK outcomes will provide a gauge for the alignment of the BOK intentions with standards of practice. Identification of the current status of formal learning, informal learning, deliberate experiences, and opportunities to measure individual learning performance should lead to discussions towards potential alignment between the academic experience and some mechanism for assessment of learning tailored to the ASCE outcomes, whether that be student-led or program-integrated assessment.

Survey Instrument Design

The survey was designed to capture "biographical" data on capstone courses through multiple choice and open-ended questions. The research team, all capstone instructors, began by sharing the details of their own courses. Through this effort, similarities and differences were noted for civil engineering capstone courses offered at the researchers' four respective universities. The team developed the survey instrument through a collaborative and iterative process of discussing their own courses. Due to the wide variation anticipated in the courses to be studied, a convergent parallel mixed methods design was chosen to collect quantitative and qualitative data within one survey.

Questions were grouped into eight categories: Course Demographics (number of terms, credit hours, typical class size, etc.), Resources (physical space, computers, and software), Grading Scheme and Structure (deliverables, weighting of deliverables, use of peer evaluations), Student Teams (number of students per team, which disciplines, how teams are formed), Mentors (external mentors, other faculty involvement, technical advisors), Projects (how many teams work on each project, how projects are solicited, nature of projects), Industry (involvement and funding), ASCE BOK Readiness.

Once the survey instrument was created in Qualtrics, two faculty members from other institutions were asked to take the survey and provide feedback on ways to improve the instrument. After comments from the two survey testers were addressed, the survey was launched through Qualtrics to the individuals identified to those on the survey distribution list. The survey was sent directly to nearly 80 civil engineering (or related fields) capstone instructors in the U.S. and Canada and further distributed through the ASCE Department Heads communication system.

To create the distribution list, emails were sent to department chairs via ASCE and ASEE with a Qualtrics survey link to identify one or two main instructors of capstone in each university. Additionally, the authors performed website searches for capstone instructors and added them to the survey distribution list. The identification of more capstone instructors continued throughout the time the survey remained open.

Verification of Instrument

To verify our survey, we compared results from prior national surveys on ABET-accredited capstone programs with our survey collected on CEE capstone characteristics with the presumption that previous surveys have been sufficiently robust and represent an appropriate level of accuracy in reporting standards of practice across the intended audience.

Our survey had responses from 57 CEE departments. The three main engineering capstone surveys, as discussed above, occurred in 1994, 2005, and 2015. In the survey performed by Todd et al (1995) in 1994, 360 departments from 221 schools responded for a response rate of

35%. Of the 360 departments, approximately about 50 were from Civil and/or Environmental Engineering (CEE) departments. A followup survey, in 2005, by Howe and Wilbarger (2006), had responses from 444 programs from 232 institutions (26% response rate from engineering programs). Of the 444 programs, approximately 60 responses were from CEE departments. Only 21 of these departments were also surveyed in 1994. The 2015 survey had respondents from 464 departments at 256 institutions, however, the authors do not report the response rate. Approximately 85 of the respondents were from Civil and/or Environmental Engineering (CEE) departments. The number of respondents in the current survey, which surveyed CEE departments only, matches well with the number of CEE respondents in the cited previous surveys.

To further verify our survey results against the prior national surveys, we compared responses between our survey and similarly worded questions on the prior surveys. Questions in the 1994 and 2005 surveys did not directly compare to our questions, however, the 2015 survey (Howe, et al.2017) included two questions that could be directly compared to questions from our survey. Table 1.1 shows the results of a question on class size for both this survey and the Howe et al (2017) survey. Both surveys follow the same trend, with the largest fraction of classes being less than 30 students (40.4% of respondents in our survey and 58.7% in the Howe et al. 2017 survey) and a similar percentage of respondents indicated their class size was over 70 students. Table 1.2 shows the results of asking CEE capstone instructors how large their typical team sizes are for both this survey and the Howe et al (2017) survey. Again, both surveys show similar percentages for each potential response, and results from both surveys are consistent in that group sizes of 4-6 are reported by ~70% of respondents. Taken together, these results indicate that the number of respondents to our survey results in consistent information when compared against a prior national level survey.

Table 1.1. Number of respondents, per class size category. Values rounded from reported percentages.

Size	**Current Survey**	**Howe et al, 2017**
Less than 20	9 (15.8%)	21 (28%)
21-30	14 (24.6%)	23 (31%)
31-40	7 (12.3%)	10 (13%)
41-50	9 (15.8%)	5 (7%)
51-70	6 (10.6%)	5 (7%)
Greater than 70	12 (21.1%)	10.5 (14%)
Total =	51 (100%)	75 (100%)

Table 1.2. Number of students per design team. Values rounded from reported percentages.

Quantity	Current Survey	Howe et al, 2017
Three or less	8 (15.7%)	8 (11.3%)
4 to 6	36 (70.6%)	50 (70.4%)
Greater than 7	7 (13.7%)	13 (18.3%)
Total =	51 (100%)	71 (100%)

Survey Responses & Summarized Observations

Summaries of survey results are presented herein and are categorized into eight major sections: Course Demographics, Resources, Grading Scheme and Structure, Student Teams, Mentors, Projects, Industry and, ASCE BOK Readiness. Multiple choice survey questions were developed for those questions expected to yield straightforward responses, which also allowed for discrete data analysis. Text-based questions were used to discover nuances and enabled the collection of qualitative data. Responses to these questions were analyzed using qualitative research methods, including the use of four independent coders. The authors reviewed and coded all responses individually then came together to discuss their respective thematic analyses and findings. The synthesized results are presented in this section of the paper.

Course Demographics

Course demographics information was collected to identify standard traits such as duration in academic terms, credit hours, and formal university catalogue information for the senior design course experience. The duration of the capstone courses varied from one to three academic terms. A large percentage (49%) of the respondents indicated the capstone experience was completed in one academic term. Forty-three percent (43%) of the respondents reported a capstone length of two academic terms. Finally, four respondents (8%) reported three academic terms were required. The majority of the programs reporting have 14-16 weeks per term (semester). A small percentage (four programs) reported having 10-12 weeks per term (tri-mester) and one program had 7 weeks per term suggesting that they are on a quarter system. The total number of credit hours for civil engineering capstone courses ranged between one and six. The wording of the question, *What is the total number of equivalent semester credit hours for your Capstone course?*, could have been interpreted by some as only the portion of the total capstone course that one specific instructor teaches (e.g. communications, report writing, etc.). That said, 5% of the respondents reported one credit hour, 2% reported two credit hours, 32% reported three credit hours, 29% four credit hours, 11% reported five credit hours, and 21% reported six credit hours.

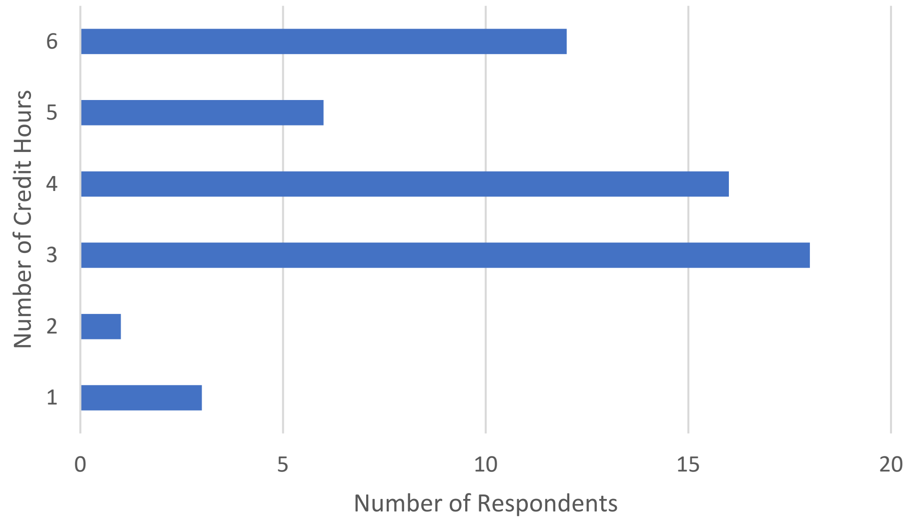

Figure 2.1. Number of respondents specifying the number of credit hours, n=56

Survey responses capturing interaction between students and the instructor of record, other faculty and/or mentors was also solicited. The number of hours allocated on average for each team for meetings with faculty members, practitioner mentor, or similar experienced guide ranged from less than one hour to more than six hours per week. The majority (61%) of the respondents specified that teams spend on average between 2 and 3 hours a week with their mentors (Figure 2). Fifty percent of the respondents serving as instructor of record specified that they spend between 3 and 6 hours per week with their students (Figure 3).

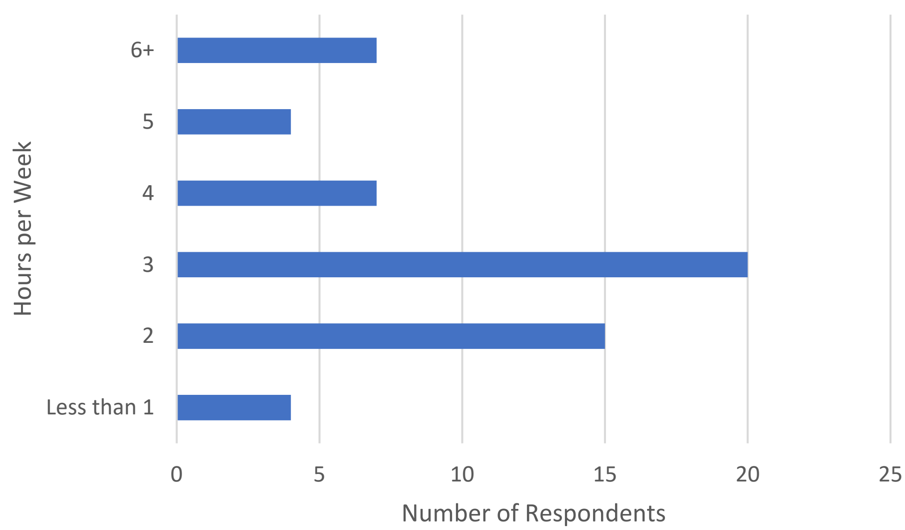

Figure 2.2. Number of weekly hours teams spend with faculty, mentors, etc. (n=57)

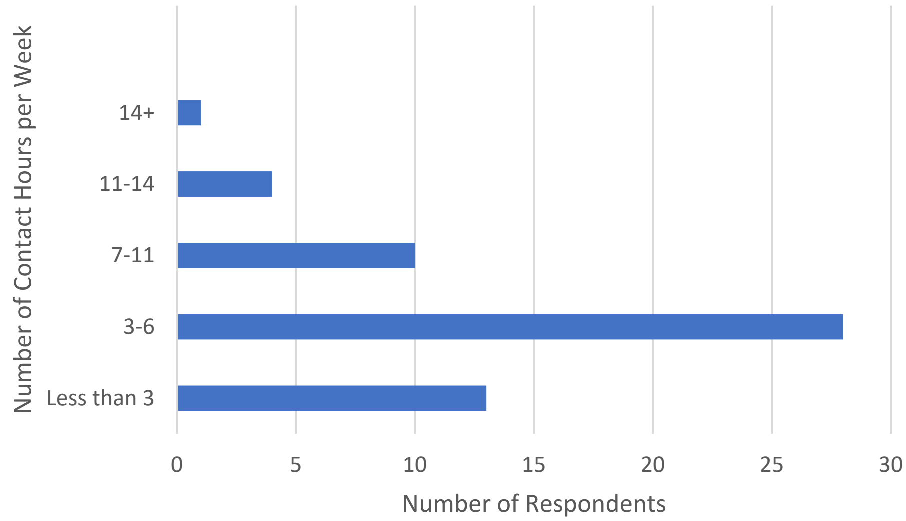

Figure 2.3. Average number of weekly hours instructors of record spend with students. (n=56)

Instructors were asked to report the typical class size. Class sizes varied from *Less than 20* to *80+* (Figure 4). Class size variations could be due to the total number of students in civil engineering programs, number of academic terms, and/or the way students are assigned to an instructor at each institution.

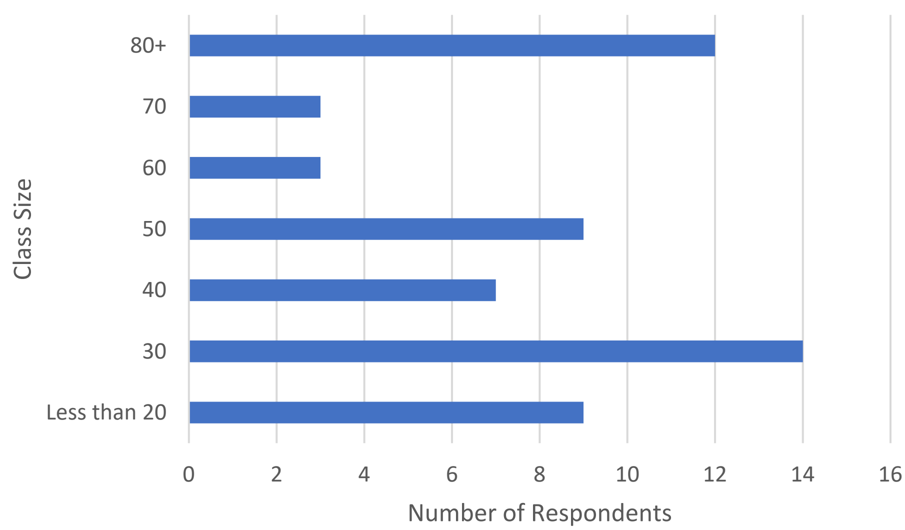

Figure 2.4. Typical class size. (n=57)

Course Resources

Several open ended questions were asked to reflect on the availability of resources in terms of physical space, experimental or testing laboratories, and computer resources and software available. The majority of the respondents stated that they use classroom and/or labs with only 14% of the respondents stating that they have a dedicated meeting space modeled after a standard office or design space (Figure 2.5). In terms of experimental/testing labs, 26% of the respondents mentioned that such space is either not available or not applicable to the work performed in senior design. A majority of respondents listed the availability of lab such as general labs, structural labs, and similar civil engineering lab spaces with the "geotechnical" lab being the most dominate response specified.

As for computer resources, the majority indicated that the course relies both on student-owned and university-owned computers to support the student work. While nearly 80% of respondents indicated university-owned computer access, only 30% of all respondents had computers dedicated to the capstone students. Faculty implied that computer labs available to the department or college were considered to satisfy the needs of the capstone students. All responses indicated students had some software available for use. The software available varied, presumably, based on the requirements of the project style provided by course instructors. Software names that were mentioned frequently included drafting software, computing software and other modelling software with structural, hydrology/hydraulics, and project management software being more commonly specified by product name. There are some trends that structures and water seem to be the dominant software used, however this could be a function many underlying conditions of the survey population such as the area of specializations of the survey participants responding, the types of programs and institutions represented, and many other traits which have not been evaluated within this preliminary survey.

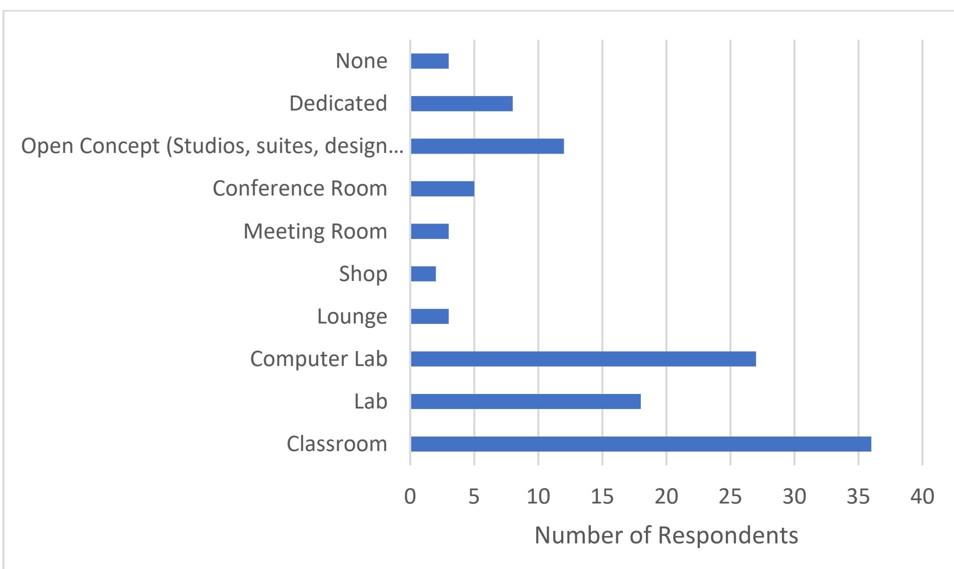

Figure 2.5. Physical space available for dedicated senior design work.

Grading Scheme and Structure

Respondents were asked to report the scoring weights assigned for each deliverable generated within the course. Results from (51) respondents (Table 2.1) indicate that a majority of courses are designed such that the final report is the most significant deliverable influencing student grades. Courses appear to be designed such that progress throughout the experience is captured and rewarded during the grading process. Responses imply that course deliverables fall into (3) primary categories: a final engineering report, some mechanisms of engagement with clients through oral presentations or meetings, and engineering drawings representing the design. Interestingly, not all respondents could categorize their course grade scheme into the deliverables identified in the survey; at least one respondent for each deliverable type indicated that the item did not contribute to the course grade. As many as 40% of respondents indicated that the engineering drawings directly related to the calculation of course grade performance. On average, a large majority of respondents indicated that progress deliverables along with the final report constitute on average 50% of the course grade. Further, these two deliverables also experience the largest variance indicating a wide spread in potential value for these specific assignments.

Table 2.1. Percentage of the course grade for each deliverable

Course Deliverables	**Percentage of Respondents Including Deliverable in Course Grade**	**Of those Included in Course Grade Scheme**				
		Min.*	**Max.**	**Ave.**	**Std. Dev.**	**Var.**
Progress Deliverables	94%	5	60	20.96	12.14	147.33
Meetings	50%	5	20	10.54	3.96	15.71
Oral Presentations	93%	5	35	17.80	7.82	61.16
Class Participation	56%	1	30	10.10	6.57	43.16
Engineering Drawings	61%	1	45	16.61	9.16	83.94
Final Report	96%	10	80	32.56	16.47	271.32
Other	61%	5	50	18.88	14.27	203.56

(*)All categories received at least (1) zero score as a minimum, indicating the category was not relevant within the course for that respondent's grading system

Measurement of team and individual efforts is performed in many variable ways, with no clear standard form. An overwhelming 80% of respondents indicated the use of peer reviews, with most, but not all, indicating peer reviews influenced grading of individual performance. Approximately 18% of respondents indicated use of CatME or similar team-management applications. Most responses indicated some form of considering individual effort as well as team performance, with clear motivation to balance the academic grading needs with reality of professional team-based project design effort with some respondents indicating that the emphasis is on the final product, as is expected by a consulting engineering firm. Some direct responses indicated that the focus was on the delivery of the final product and not specifically on balancing effort and others indicated that students were provided reflection activities and self-assessment opportunities such that the experience was more about introspection than assessment of each individual student.

Student Teams & Mentor Assignments

Student team creation and formation information was also collected. Respondents were given three choices in reporting team sizes (2-3, 4-6, 7+); the most common team size (70%) reported was 4-6 members. A majority of respondents stated that the student groups were assigned by faculty (59% response rate), including not only the course faculty, but other faculty familiar with student interests and skill level. Approximately half of responses indicated that team assignments were influenced by student input in the form of student interest surveys, interviews, and self-assessment exercises.

External (non-university affiliates) mentors were reported as valuable to the capstone structure and information was collected related specifically to quantity of mentors partnering with teams and the roles of these individuals within the projects. Table 2.2 shows that the majority of respondents had 1 faculty involved in the capstone project (49% of the respondents), and more than 5 external members involved in the project (35% of the respondents). The number of mentors varied based on the class size and team sizes. With the survey responses indicating an average class size of 45 students and majority of team sizes including 4-6 students, the response results for external mentors indicates that courses likely align no more than one external mentor per design team. Responses indicated that faculty involvement included individuals in addition to the assigned course instructor, with 55% of respondents indicating that multiple faculty were assigned as mentors to student teams. An additional 35% of respondents indicated that while faculty were not formally assigned to advise teams, students were provided opportunities and even encouraged to contact other faculty members to provide discipline-specific mentorship.

Table 2.2. Identifying the number of faculty or external members involved in the project

Number of faculty or external members involved	**1**	**2**	**3**	**4**	**5+**	**other**
Number of faculty members involved	49%	23%	10%	4%	8%	6%
Number of external members	12%	8%	4%	10%	35%	31%

Technical Advisors & Industrial Involvement

Technical advisors, be they external engineers or internal faculty not serving directly as course instructors, are used in a variety of different ways and no clear trend is evident from the survey responses regarding the role of advisors within projects or the means to recruit advisors for teams. Most indicate that the role of the technical advisor was to provide technical mentorship directly relevant to the analysis and design work being performed for the project. Very few indicated these advisors served to perform evaluation or assessment of student work. Nearly 45% of responses indicated the technical advisors were licensed professional engineers.

Industry member involvement is consistent; however, the engagement varies as shown in Figure 2.6. Similar to technical advisors, industry members serve as technical experts and mentor students during the design project. Unlike the technical advisor role which appears to be limited to project guidance, industry members appear to take on broader roles that span from project conception, through the design experience, and culminating in measuring student success. Recruitment of external technical advisors, from industry, was reported and a variety of mechanisms across the programs were identified. The majority of the respondents mentioned that industry mentor contact is through networking (29%) and directed emails to individuals in local practices (28%). Very few have an official application process and the relationship is reported as typically unfunded.

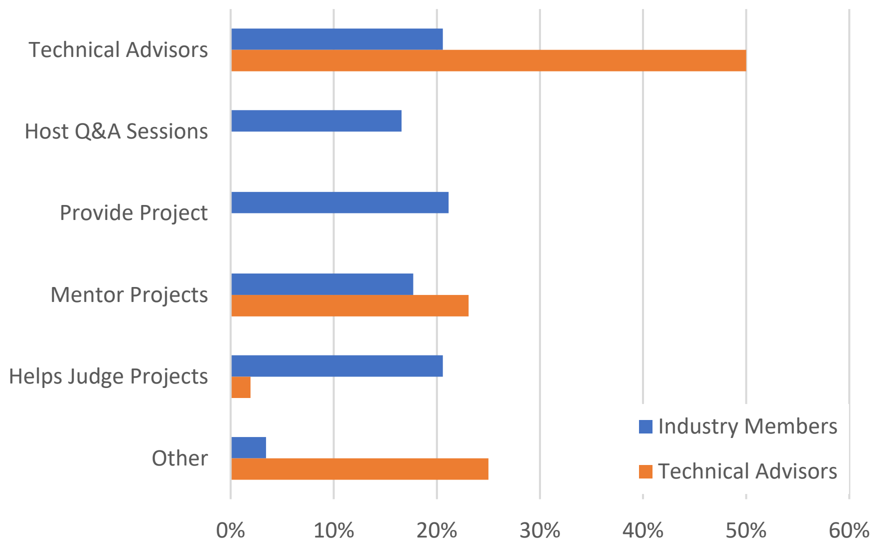

Figure 2.6: Industry member and Technical advisor involvement in capstone experience.

Projects

Survey responses were also collected to obtain information on team composition, project types, and methods to solicit projects. Survey responses indicated that most project were multi-disciplinary within the realm of civil engineering with a minority of responses indicating partnerships with disciplines such as mechanical engineering, electrical engineering, or geology departments. Broadly, responses indicated that most teams were comprised of students representing two or more civil engineering disciplines. Average responses indicated that teams composed of 2-3 different disciplines on average. The majority of the respondents stated that all student teams in a given course work on different projects (Figure 10). A variety of project types were reported, such that 49% of the respondents stated that they give real projects, 15 % give fictitious projects and 36% give modified real projects. Projects were reported as approximately 75% being solicited from industrial partners and only the remaining 25% being generated internally. Project solicitation varies widely from a very formal process that comes in to an informal process. Examples include online portals for industry professionals to submit project ideas, hosting an industry pitch night and a network of industry that submits projects regularly. In general, most of the respondents who specified that they solicit projects from industry stated that they must have a major design element. Requests for projects were relatively similar in that faculty requested industry partners to provide "framed" projects such that they could be applied in the academic setting, with some projects reduced in scope, some partners providing site-specific data, and other projects refined to fit team sizes or specific disciplines of students assigned to the team. Many indicated industrial partners not only provided projects but served as points of contact for the student team, supporting the team as technical mentors or role play as client representatives.

BOK Readiness

As may be expected, variability of "readiness" for the ASCE BOK exists across the (5) diverse outcomes. Three trends appear to be evident, notably: Critical Thinking and Problem Solving is prevalent, assessment of individual performance is not standard practice for most programs across most abilities, and formal learning opportunities for many outcome abilities do not appear to be integrated into the capstone course. Reporting indicates that nearly 90% of programs host formal learning opportunities in two of the three Critical Thinking abilities. While students are presented with formal course learning opportunities, less than 65% of the programs assess student performance at the individual level. Assessment at the individual level for all other outcomes is significantly lower, with an average of 45%. However, while current individual assessment may not occur, less than 10% of programs reported as "not ready" to perform individual assessments, with the exception to two Social Science abilities. Nearly 20% of programs indicated as "not ready" to assess the ability for individual students to explain and apply concepts and principles of social sciences. Lastly, the survey results imply that few of these abilities are formally associated with other curriculum or coursework in the program. On average, fewer than 31% of programs indicated that these abilities are formally associated with curriculum. Results from the survey require some interpretation and additional data should be obtained before more accurate conclusions can be made; but all reporting institutes indicated that (5) abilities related to Critical Thinking and Teamwork are solely contained in senior design and have no formal presences in other curriculum activities or coursework.

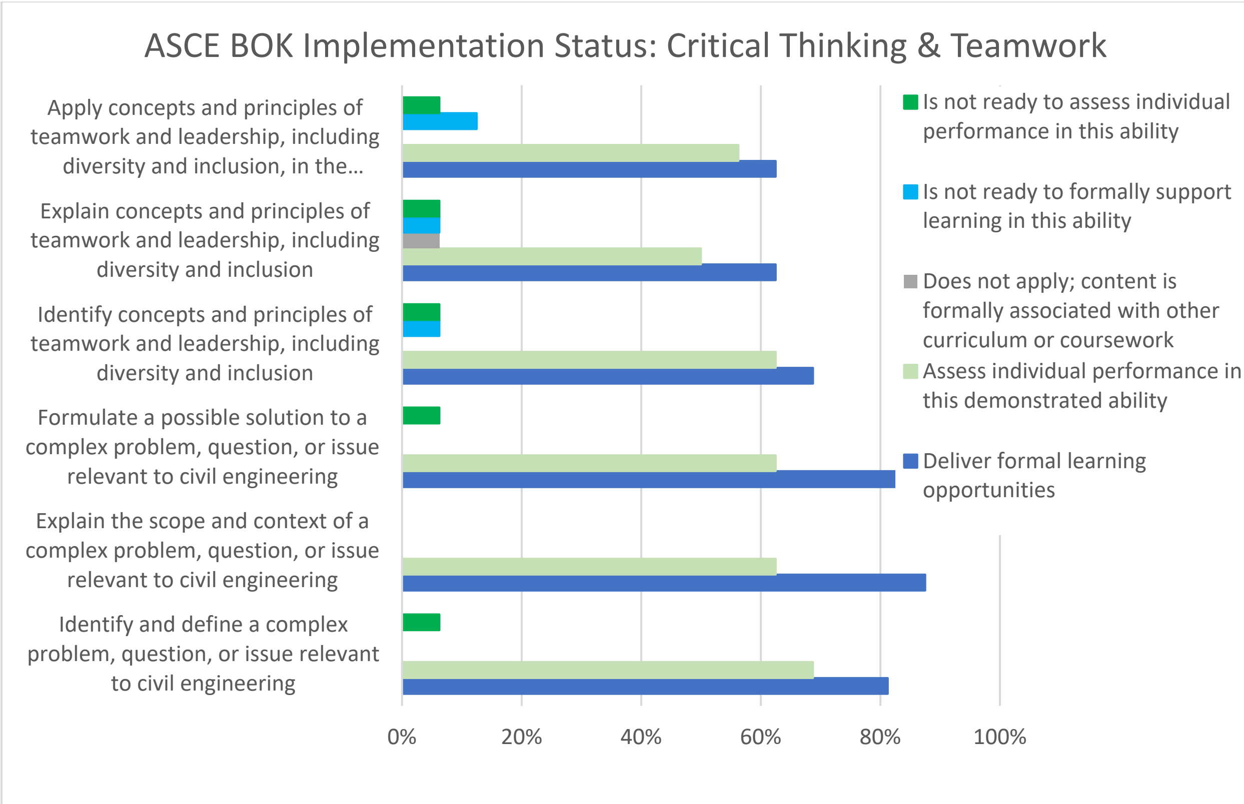

Figure 3.1. ASCE BOK Implementation Survey Results

Summary

The survey results received demonstrate the variety of experiences in a capstone course within the participating civil and environmental engineering programs. Some trends indicate that strong industry involvement, recognizable resource availability including access to spaces such as labs and computing space, and deliberate mentorship engagement are highly active, valuable to the professors, and can be considered standards of practice across most experiences. Ultimately, capstone experiences have been recognized as significant academic exercise during which faculty have designed formal learning opportunities often paired with evaluation and assessment efforts related to many elements of design mapped fairly well to the ASCE Body of Knowledge.

References

Accreditation Board for Engineering and Technology, Inc. (2019). Criteria for Accrediting Engineering Programs. Effective for Reviews during the 2020-2021 Accreditation Cycle Incorporates all changes approved by the ABET Board of Delegates Engineering Area Delegation as of November 2, 2019. Retrieved from https://www.abet.org/wp-content/uploads/2020/03/E001-20-21-EAC-Criteria-Mark-Up-11-24-19-Updated.pdf

Association of American Colleges & Universities. (2009). Member Survey Findings. Retrieved from https://www.aacu.org/about/membership/surveytalkingpoints. https://www.aacu.org/leap/hips

Aidoo, J., & Sipes, S. M., & Hanson, J. H., & Lovell, M. D. (2013, June), *Capstone Design Alumni Survey* Paper presented at 2013 ASEE Annual Conference & Exposition, Atlanta, Georgia. https://peer.asee.org/19283

Brouwer, R., & Sykes, A., & VanderLeest, S. H. (2011, June), *Entrepreneurial Mindset Development in a Senior Design/Capstone Course* Paper presented at 2011 ASEE Annual Conference & Exposition, Vancouver, BC. https://peer.asee.org/17913

Fries, R., & Lakkaraju, S. K., & Cross, B., & Morgan, S. M., & Welker, A. L. (2012, June), *Survey of Civil Engineering Assessment Changes in Response to Revised ABET CE Program Criteria* Paper presented at 2012 ASEE Annual Conference & Exposition, San Antonio, Texas. https://peer.asee.org/21974

Haave, N.C. (2015). Survey of Biology Capstone Courses in American and Canadian Higher Education: Requirement, Content, and Skills. *Bioscene* Volume 41(2) December 2015

Henscheid (2000), Professing the disciplines: An analysis of senior seminars and capstone courses (Monograph No. 30). Columbia, SC University of South Carolina, National Resource Center for the First Year Experience and Students in Transition.

Howe, S., & Wilbarger, J. (2006, June), *2005 National Survey Of Engineering Capstone Design Courses* Paper presented at 2006 Annual Conference & Exposition, Chicago, Illinois. https://peer.asee.org/1023

Howe, Susannah; Rosenbauer, Laura; and Poulos, Sophia, (2017) "The 2015 Capstone Design Survey Results: Current Practices and Changes over Time". *Engineering: Faculty Publications*, Smith College, Northampton, MA. https://scholarworks.smith.edu/egr_facpubs/9

Martonosi, S.E., D. Williams, T.D. (2016) A Survey of Statistical Capstone Projects, *Journal of Statistics Education*, 24:3, 127-135, DOI: 10.1080/10691898.2016.1257927

McKenzie, L. J., Trevisan, M. S., Davis, D.C., Beyerlein, S.W. (2004). Capstone Design Courses and Assessment: A National Study. In *Proceedings of the 2004 American Society of Engineering Education Annual Conference & Exposition*

Nelson, J., & Hollenbaugh, E., & Borup, M. B. (2014, June), *Using Sponsored Design Projects to Strengthen Professional Practice Curriculum Components in Civil Engineering Capstone* Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana. https://peer.asee.org/23277

Padmanabhan, G, Katti, D, Khan, E., Peloubet, F., Leelaruban, F (2018). A Unique Civil Engineering Capstone Design Course. *International Journal of Engineering Pedagogy* Vol 8, No 1 (2018)– eISSN: 2192-4880

Padgett, R.D., & Kilgo, C.A. (2012) 2011 National Survey of Senior Capstone Experiences: Institutional-level data on the culminating experiences (Research Reports on College Transitions No. 3) Columbia, SC University of South Carolina, National Resource Center for the First Year Experience and Students in Transition.

Saleh, N. (2011, June), *Collaborative Information Behaviour of Engineering Students in a Senior Design Group Project: a Pilot Study* Paper presented at 2011 ASEE Annual Conference & Exposition, Vancouver, BC. https://peer.asee.org/17615

Shah, D, Kames, E., Clark, M.C., Morkos, B (2019) Examining the Differences in Student Motivation for Industry Projects and Non-Industry Projects in Senior Capstone Design. *126th ASEE Annual Conference & Exposition 2019*

Silverstein, D. L., & Bullard, L. G., & Seider, W. D., & Vigeant, M. A. (2013, June), *How We Teach: Capstone Design* Paper presented at 2013 ASEE Annual Conference & Exposition, Atlanta, Georgia. https://peer.asee.org/19689

Solnosky, R., & Phillips, J. J. (2019, June), *Benchmarking Architectural Engineering Capstones* Paper presented at 2019 ASEE Annual Conference & Exposition , Tampa, Florida. https://peer.asee.org/32144

Todd, R., Magelby, S., Sorenson, C., Swan, B., and Anthony, D. (1994) "A Survey of Senior Projects or Capstone-Type Engineering Courses in North America," *Proceedings of the Advances in Capstone Education Conference*, Brigham Young University, 1994, pp. 3-12.

Young, D. G., Chung, J.K., Hoffman, D.E.,&Bronkema, R. (2017). 2016 2016 National Survey of Senior Capstone Experiences: Expanding our Understanding of Culminating Experiences. (Research Reports on College Transitions No. 8). Columbia, SC: University of South Carolina, National Resource Center for The First-Year Experience & Students in Transition.