BOARD # 55: Senior capstone case study: measuring outcomes with enhanced industry mentoring

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Abstract

Significant changes were implemented into the senior design capstone course for civil and environmental engineering students over the course of an eleven-year period from academic year (AY) 2012–2013 to AY 2023–24. This course now takes place over two semesters in the final AY of the undergraduate programs for civil and environmental engineering students. Major year-over-year changes made – against which experiences and outcomes were measured – included the instructors reducing group sizes and increasing the number of external mentors involved in the class, altering project deliverable targets, and implementing more frequent external mentor meetings; the instructors doubling the frequency of peer evaluations and time sheet graded feedback to students and also setting aside dedicated in-class time for external mentors to market themselves and their companies; and the instructors adding general contractors (GCs) as external mentors to the course, supplementing the civil and environmental designed-focused mentors in the course.

Measured outcomes from the changes in the senior capstone course included student experience as measured via formal, anonymous, and university-administered course and instructor feedback (CIF) surveys and instructor-administered course-specific surveys; mentor experience as measured via instructor-administered course-specific surveys; and student and employer (i.e., "student-employment") experience as measured by instructor-administered course-specific surveys, specifically the proportion of students who ultimately accepted employment offers from mentors' companies, and reported starting salaries with year-over-year increases that improved relative to salaries from previous civil and environmental engineering graduates and also generally outpaced college, industry, and national trends.

The changes made to the case study capstone course represent an apprenticeship-style learning experience historically associated with construction trades. Thus, the relevance of this study to the civil engineering community applies to both academics and professionals as the measured outcomes due to changes made in the case study capstone course represent "real-world" early-career impacts on students and their employers. Senior capstone is an excellent forum to measure the effects of course changes since most students in this program enter the workforce almost immediately after the completion of the capstone, thus providing some control to the experiment. Provisional conclusions from the measured outcomes include improved student experience in CIF surveys, improved and now consistent mentor experience despite the heavier time demands, increasing rates of students accepting positions with employers who participated in the senior capstone course, and starting student salaries with year-over-year inflation-adjusted increases that generally outpace college, industry, and national trends.

Introduction and motivation

The American Society for Engineering Education (ASEE) Civil Engineering Division Committee on Professional Practice is uniquely interested in evaluating the capstone experience, particularly in regard to the capstone students' experience of "real-world" practice [1]. Furthermore, capstone courses are often used to meet several student outcomes (SOs) for ABET [2] accreditation, especially regarding the students' improvements in identifying, formulating, and solving complex "open-ended" engineering design problems to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as social, environmental, and economic factors.

Preparing students for "real-world" practice with simulated "open-ended" design experiences with multiple and often competing goals is thus a critical component of the undergraduate learning experience. Success in creating this experience in a traditional instructor-led classroom structure can be limited due to the following factors:

- Having a wide range of project topics to meet a variety of student majors, concentrations, and career interests in a single classroom, especially in the capstone which typically has all students from a major or multiple major(s) participating in it;
- Having enough projects to keep group sizes optimal without having multiple groups working on the same project lest they collaborate and effectively work as a larger group;
- Having an open-ended design problem with enough regular, expert mentorship meetings to effectively guide the students to viable solutions and design deliverables without "hand-holding" the students toward a specific set of solutions; and
- Defining an appropriately complete and robust yet approachable target for design deliverables with a structure that is flexible enough to accommodate a range of projects while maintaining a sense of fairness across all student groups.

Research questions and corresponding precedents regarding the state-of-the-art

The following research questions (RQ) were established for evaluating existing literature pertaining to the current study.

- RQ1. What are the best practices for adding or enhancing the level of involvement of external industry mentors into the civil and environmental engineering capstone, in regard to project type, targeted deliverables, meeting structures, student group structures, and other factors?
- RQ2. What are the best measurements to evaluate student experience outcomes of enhancing the level of involvement of external industry mentors into the capstone that are not already addressed via the ABET evaluation process?
- RQ3. What are the best measurements to evaluate the mentor experience and student-employment outcomes for which there are comparatively fewer precedents?

To identify published research precedents for the RQs, a truncated systematic literature review (e.g., truncated PRISMA [3]) was carried out. The phrase "civil engineering capstone" was searched for within the ASEE PEER [4] database in the fields of title, conference session name, document content, tagged topics, and tagged divisions, resulting in 135 relevant records. Note that "environmental engineering" was deliberately not included in the search phrase given the comparatively rarer nature of environmental engineering being in department names or being a stand-alone major. A cursory manual review of the results indicated that the topic of "sustainability" was common within these results albeit being unrelated to the current RQs. Thus "sustainability" was excluded, resulting in 51 relevant records. Finally, a filter was applied to limit the results to more recent studies, based on the assumption that more recent studies included and improved upon the results from older studies. By filtering for articles published after January 1, 2014, the remaining relevant database included 19 records. The titles and abstracts of these 19 articles were manually reviewed for relevance to exclude articles where the capstone course was a cursory subtopic to another primary topic such as professional licensure, or more generally, articles that did not address the current RQs. The database Web of Science [5] (WoS) was also utilized, albeit comparatively less formally. The phrase "engineering capstone" was searched for in the topic field with no limitation made on date of publication, resulting in 1,723 relevant records. The records were ranked by relevance according to the WoS algorithm, and the titles and abstracts of the top 20 most relevant articles were manually reviewed for duplications with the ASEE PEER search as well as relevance to the current RQs, excluding several articles that pertained explicitly to ABET accreditation and systems engineering capstones. Finally, a few additional relevant articles were manually discovered through casual searches in the ASEE PEER, particularly through older articles.

Past researchers on capstone courses have examined the difference between two common scenarios found in capstones, being (1): Industry mentors provide projects and serving as stakeholders, but are not involved in regular project mentoring, and (2): Industry mentors provide projects and are involved in regular project mentoring, setting deliverable scopes, and holding students to deadlines. Generally speaking, higher levels of external mentor involvement (i.e., scenario 2) correlate with more positive student experiences [6, 7] especially in the context of "open-ended" design problems sans formulaic solutions [8]. Previous pedagogical research at the university level [9, 10] has revealed the value of smaller group sizes (e.g., ideally less than 4 students) in improving the efficiency of decision-making, work allocation, and deliverable production versus larger group sizes. Nonetheless, the vast majority of capstone projects in a widespread survey have student project groups with 4 or more students [11]. Past researchers have also identified positive student experience outcomes when projects used are "real-world" rather than hypothetical projects [12], when projects are existing (i.e., already constructed or at least designed) rather than current or future projects [13], and when student deliverables require substantial creative and critical-thinking input from students [14]. To achieve all of these goals, external industry mentors serve as the primary and regular technical advisors (i.e., meeting frequently with students) due to limited capacity from faculty alone to meet all of these targeted criteria for a wide variety of real-world projects with small teams, and thus a larger number of teams [15]. There is more limited research regarding surveys of mentor experience [16] as well as student-employment outcomes [17].

History of capstone changes for the current case study course

The senior capstone course was first introduced in the University of Notre Dame (ND) Department of Civil & Environmental Engineering & Earth Sciences (ND CEEES) in the Spring 2013 semester as a one-semester elective course. The following two academic years (AY), it was required as a one-semester course for all graduating students majoring in civil engineering except for those students who participated in NDSEED (i.e., international bridge design and construction project) which substituted as the “design capstone” experience for purposes of ABET. Starting in AY 2015-16, the course was changed to occur in both semesters for the AY and remained semi-required as before, excepting NDSEED students who typically numbered less than 15% of the number of students enrolled in the capstone class. In that same AY 2015–16, the first cohort of environmental engineering seniors (i.e., a separate ABET-accredited degree within ND CEEES now distinct from civil engineering) participated in the capstone course.

The capstone course’s role in the departmental and major curricula remained unchanged until the course became required for all civil and environmental engineering seniors starting in AY 2023–24. As exhibited later, the role of the course in the curricula (i.e., whether it is required or not and for whom) may have an effect on measured outcomes, particularly the student experience. Thus, it is within the timeframe of departmental curricular role consistency for the capstone course – AY 2015–16 to AY 2023–24 – that changes made within the course structure itself were evaluated herein.

Changes to the course over the entire time period considered are briefly summarized in **Table 1**. Starting in the AY 2020–21, the instructors introduced “major changes” (herein referred succinctly to as such) to the project teams, projects, and mentorship structures. As a result, the start of the AY 2020–21 academic year was used as a delineation when comparing measured experiences in a multitude of ways herein. Specific changes made during the AY 2020-21 were as follows:

- Group sizes were reduced from having four, five, or six students per group to a targeted three students per group, with four students used in a group only when necessary due to the number of students with stated project type preferences (based on surveys administered both in the preceding Spring semester during the students’ junior year as well as again at the start of the Fall semester).

- The number of external mentors was greatly increased and their involvement in the class was also greatly increased. Prior to AY 2020–21, there was approximately one mentor for every eight to twelve students in the class (mentoring two groups each, usually). As a result, faculty themselves met with the student groups weekly to discuss project progress, and mentors typically only met with groups once per month. Hence, faculty were much more involved with details of the design projects compared to the mentors. Starting with AY 2020–21, there is now only one mentor (and often a team of mentors from the same company and department) per student group of three or four students. Furthermore, these mentors are asked to meet with students for up to one hour once per week during both semesters. Guidelines provided to mentors and shared with students so all parties understand shared expectations can be provided by request to the authors.

Table 1. Summary of history of capstone course changes

<table>
<tr><th>Semester</th><th>Approx. month-year of the start of semester</th><th>Role of course in department and major curricula</th><th>Major changes in course and project structures</th><th>No. of students enrolled in course</th><th>Typical no. of students in each group</th><th>Typ. no. of groups per mentored project</th></tr>
<tr><td>Spring 2013</td><td>Jan-13</td><td>Elective, 1 semester only</td><td>Capstone course initially created, no external mentors</td><td>7</td><td>7</td><td>1</td></tr>
<tr><td>Spring 2014</td><td>Jan-14</td><td rowspan="2">Semi-required, excepting students in NDSEED, 1 semester only</td><td></td><td>38</td><td rowspan="12">4 – 6</td><td rowspan="12">1 – 2</td></tr>
<tr><td>Spring 2015</td><td>Jan-15</td><td></td><td>39</td></tr>
<tr><td>Fall 2015</td><td>Jul-15</td><td rowspan="16">Semi-required, excepting students in NDSEED, 2 semesters</td><td rowspan="2">Enviro. engineering project(s) added</td><td>56</td></tr>
<tr><td>Spring 2016</td><td>Jan-16</td><td>56</td></tr>
<tr><td>Fall 2016</td><td>Jul-16</td><td></td><td>63</td></tr>
<tr><td>Spring 2017</td><td>Jan-17</td><td></td><td>63</td></tr>
<tr><td>Fall 2017</td><td>Jul-17</td><td>External mentors first used in the class but in a limited capacity</td><td>38</td></tr>
<tr><td>Spring 2018</td><td>Jan-18</td><td></td><td>38</td></tr>
<tr><td>Fall 2018</td><td>Jul-18</td><td></td><td>59</td></tr>
<tr><td>Spring 2019</td><td>Jan-19</td><td></td><td>59</td></tr>
<tr><td>Fall 2019</td><td>Jul-19</td><td></td><td>61</td></tr>
<tr><td>Spring 2020</td><td>Jan-20</td><td></td><td>60</td></tr>
<tr><td>Fall 2020</td><td>Jul-20</td><td rowspan="2">Major changes to team, project, and mentorship structures began</td><td>52</td><td rowspan="10">3 – 4</td><td rowspan="10">1</td></tr>
<tr><td>Spring 2021</td><td>Jan-21</td><td>52</td></tr>
<tr><td>Fall 2021</td><td>Jul-21</td><td rowspan="2">Increased freq. of feedback and began dedicated in-class industry recruiting sessions</td><td>54</td></tr>
<tr><td>Spring 2022</td><td>Jan-22</td><td>54</td></tr>
<tr><td>Fall 2022</td><td>Jul-22</td><td rowspan="2">General contractor (GC) projects added</td><td>40</td></tr>
<tr><td>Spring 2023</td><td>Jan-23</td><td>40</td></tr>
<tr><td>Fall 2023</td><td>Jul-23</td><td rowspan="2">Required, 2 semesters</td><td></td><td>57</td></tr>
<tr><td>Spring 2024</td><td>Jan-24</td><td></td><td>57</td></tr>
<tr><td colspan="7">Note that the approximate month and year of the start of each semester is included in the second column and was used in other tables and figures throughout this paper to ensure convenient time units in charts and tables. Technically, the Fall semester begins in August, but the faculty efforts to run a successful capstone course must begin in earnest no later than July, so July is used as the start month for identifying the Fall semester. The use of January and July as start months also provides even 6-month timesteps in the charts provided hereafter.</td></tr>
</table>

- In the current form of the class, mentors are comparatively more involved in guiding students on the specific details and target deliverables of the projects while the faculty now focus more time on recruiting appropriate mentors with viable projects, scheduling mentor-student meet-ups in class and off campus, managing the mentor-student relationships and expectations as questions and occasional tensions arise, tracking down and providing resources needed for each specific project (e.g., software, textbooks, codes and standards, test equipment, etc.) as technical needs arise, and surveying individual students and teams regarding work efforts (via weekly timesheets) and teammate support (via peer evaluations twice per semester). Hence, faculty involvement is now more administrative than traditionally "instructive" in the course with these changes.

- Prior to AY 2020–21, targeted project deliverables were typically more extensive and scoped beginning at the preliminary stages of design processes to include proposals, basis of design reports, preliminary cost estimates, environmental impact reports, and alternative schematic designs. Furthermore, the chosen case study projects were typically projects that had not yet been awarded nor further developed by the mentors themselves (e.g., the "real-world" projects were still at the RFP stage or near it.) Students struggled to complete their final construction documents substantially due to the large number of early-stage deliverables, alternatives, and outstanding design parameter unknowns. Starting with AY 2020–21, most projects now begin with the project already have been "awarded" and mentors are recommended to use projects they have worked on substantially themselves already. Students in design projects are expected to deliver "schematic" construction documents or environmental remediation analysis documents (i.e., approximately 20–30% complete) in the Fall semester and "permit" construction documents or environmental remediation analysis documents (i.e., approximately 90% complete) at the end of the Spring semester. The completion of other deliverables is at the discretion of the mentor but is generally limited versus preceding years.

While the most significant changes within the capstone course itself began in AY 2020–21, other noteworthy changes have been made since then based on mentor and student feedback. Starting in AY 2021–22, the instructors doubled the frequency of peer evaluations and time sheet graded feedback to students in order to identify and intervene with students lagging behind on either effort earlier in each semester. Mentor feedback following the AY 2020–21 course provided a number of valuable recommendations for improvement, but the most common request from mentors was that they have the opportunity to interact directly with and recruit all students in the class rather than just the students on their mentored team. As a result, instructors set aside dedicated in-class time for external mentors to market themselves and their companies in the Fall semester each AY starting in AY 2021–22. Most mentors participate in person, and the remainder participate virtually. Mentors are assigned 12–15 minutes each to present their companies, projects, and careers to all relevant students. Seniors in the course are required to attend, but all students in the department at all levels are invited to join. These sessions typically occur in parallel tracks to provide the best value for both students and recruiters; for example, there are civil engineering recruiters in one room and environmental engineering recruiters in another room. Instructors then host a "meet and greet" with a light lunch afterwards for all parties to interact casually with one another. Interested recruiters are able to schedule formal interviews later in the day.

Starting in the AY 2022–23, the instructors added general contractors (GCs) as external mentors to the course, supplementing the civil and environmental designed-focused mentors in the course. Note that approximately 20% of all ND CEEES graduates begin their careers with GCs, and about the same proportion of rising seniors indicate a preference to work on GC-led projects. An instructor with GC industry experience joined the faculty team to help launch these projects, which was necessary and valuable due to the differences in typical efforts and deliverables between designers and GCs in practice. Design-build projects work especially well in the context of the capstone course given the inherent need for some design efforts, but several traditional design-bid-build projects have been implemented successfully as well. Other researchers have provided guidance how best to evaluate construction management-type projects [18].

Measuring the student experience

The university administers anonymous surveys to students at the end of each academic semester called "course instructor feedback" (CIFs), in which there are a multitude of questions pertaining to the course and the instructors. Some questions seeking nuanced feedback are "open answer." Of the questions with limited response options, the questions pertaining to the class itself include the following:

- "Intellectual challenge" with response options being extremely high, very high, somewhat high, moderate, somewhat low, or very low.
- "Time outside class" with response options being 15+ hours/week, 11-14, 8-10, 6-7, 4-5, 2-3, or 0-1.
- "I felt engaged in this course" with response options being strongly agree, somewhat agree, somewhat disagree, strongly disagree, or not sure/no opinion.
- "The assignments promoted my learning" with response options being strongly agree, somewhat agree, somewhat disagree, strongly disagree, or not sure/no opinion.

The student responses to the CIFs for the four aforementioned course-focused questions with limited response options are tabulated in **Table 2**. Recalling the consistent role of the capstone course in the departmental curricula from AY 2015–16 to AY 2023–24 and the aforementioned major changes initiated in AY 2020–21, delineations are made in **Table 2** and other tables and charts herein for these respective time periods in order to determine the size and statistical significance of differences in measured experience for course constituents (the constituents being students in the case of **Table 2**). Note that the major changes made to the course starting in AY 2020–21 resulted in significant improvements (both size and statistical) in the four aforementioned student responses regarding course content. Of particular note, the mean time outside of class that students worked for the course nearly doubled from 4.2 hours/week to 8.1 hours/week between the two evaluated time periods. Instructors occasionally express concern regarding there possibly being an inverse correlation between increasing the workload in their classes and the positivity of the student experience, especially in the cases of "open-ended" design projects. In contrast, the instructors for the case study capstone course being evaluated herein identified a positive correlation between these measures.

Table 2. Student responses to CIFs regarding intellectual challenge, time spent, engagement, and learning

Approx. month-year start of sem.	Credit hours	Student resp. rate %	Intel. chal. % extr or very high	Stats. intel. chal. % extr or very high	Time (hrs) outside class per week	Stats. time (hrs) outside class per week	% students who felt strongly engaged	Stats. % students who felt strongly engaged	% students who felt strongly learning promoted	Stats. % students who felt strongly learning promoted
Jan-13	3	86	100	-	6.6	-	83	-	50	-
Jan-14	3	74	61	-	5.5	-	63	-	48	-
Jan-15	3	87	47	-	5	-	56	-	63	-
Jul-15	1	82	46	Mean: 43.3 SD:15.9	2.9	3-credit sems. only Mean: 4.2 SD: 0.63	46	Mean: 44.0 SD: 13.5	48	Mean: 41.3 SD: 14.5
Jan-16	3	79	57		4.5		51		49	
Jul-16	1	71	49		3.1		47		35	
Jan-17	3	73	63		4.6		49		44	
Jul-17	1	92	34		3.3		54		51	
Jan-18	3	87	61		4.4		67		67	
Jul-18	1	92	28		2.8		42		40	
Jan-19	3	86	51		4.5		38		40	
Jul-19	1	79	17		2.8		24		24	
Jan-20	3	68	27		3.1		22		15	
Jul-20	1	90	68	Mean: 71.7 SD: 11.8 Mean diff.: +28.4, *p*-value: 0.002, 95% CI [12.3, 44.5]	4.3	3-credit sems. only Mean: 8.1 SD: 0.35 Mean diff.: +3.9, *p*-value: 0.0001, 95% CI [2.9, 4.8]	74	Mean: 77.7 SD: 11.2 Mean diff.: +33.7, *p*-value: 0.0002, 95% CI [19.6, 47.8]	74	Mean: 81.0 SD: 14.3 Mean diff.: +39.7, *p*-value: 0.0001, 95% CI [23.7, 55.7]
Jan-21	3	87	91		8.4		84		91	
Jul-21	1	87	66		4.2		57		55	
Jan-22	3	80	79		8.1		79		86	
Jul-22	1	75	57		4		85		93	
Jan-23	3	80	69		7.7		87		87	
Jul-23	1	90	47	-	3.5	-	67	-	65	-
Jan-24	3	77	84	-	7.8	-	75	-	77	-

The capstone course evaluated herein has always been team-taught by multiple faculty members, typically with two or three instructors and as many as four. Many of the CIF questions are specific to each individual faculty member. Of the questions with limited response options, the students are asked to evaluate the following criteria specific to each instructor: Organization, resources, assignments, feedback, preparation, clarity, fairness, develop mastery, stimulate interest, and promote thinking. The limited response options for each of these criteria are as follows: excellent, very good, good, poor, and very poor. Each of these qualitative response options is converted into a numerical value ranging from 5 to 1, respectfully, and a CIF composite median score between 5.0 and 1.0 is computed for each instructor. This CIF composite median score is generally the single value from the CIFs most closely tracked by supervisors regarding instructor performance in a course. Note the large (and statistically significant in the case of Professor A) differences in CIF composite median and proportional evaluation scores as shown in **Table 3**, **Table 4,** and **Figure 1** due to the major changes enacted in AY 2020–21.

Table 3. Student responses to CIFs regarding overall course experience for Prof. A

Approx. month-year start of sem.	**Professor A (no data for Jan-24)**					
	CIF composite median	**Stats. CIF comp. median**	**Comp. % excel. or very good**	**Stats. comp. % excel. or very good**	**Comp. % very poor or poor**	**Stats. comp. % very poor or poor**
Jan-13	4.6	-	97	-	0	-
Jan-14	3.6	-	58	-	1	-
Jan-15	4.0	-	71	-	2	-
Jul-15	3.7	Mean: 3.76 SD: 0.35	55	Mean: 59.6 SD: 8.5	7	Mean: 6.4 SD: 3.9
Jan-16	4.1		68		2	
Jul-16	3.9		67		2	
Jan-17	4.0		63		5	
Jul-17	3.9		62		6	
Jan-18	4.0		70		4	
Jul-18	3.0		42		12	
Jan-19	3.9		57		6	
Jul-19	3.3		52		14	
Jan-20	3.8		60		6	
Jul-20	4.6	Mean: 4.70 SD: 0.30 Mean diff.: +0.94, *p*-value: 0.0001, 95% CI [0.57, 1.31]	87	Mean: 82.7 SD: 8.5 Mean diff.: +23.1, *p*-value: 0.0001, 95% CI [13.7, 32.5]	0	Mean: 1.2 SD: 1.6 Mean diff.: -5.2, *p*-value: 0.008, 95% CI [-8.9, -1.62]
Jan-21	5.0		91		0	
Jul-21	4.2		70		2	
Jan-22	4.6		75		4	
Jul-22	5.0		90		0	
Jan-23	4.8		83		1	
Jul-23	4.1	-	70	-	1	-

Table 4. Student responses to CIFs regarding overall course experience for Profs. B – D

Approx. month-year start of sem.	Professor B				Professor C			Professor D		
	CIF comp. median	Mean CIF comp. median	Comp. % excel. or very good	Comp. % very poor or poor	CIF comp. median	Comp. % excel. or very good	Comp. % very poor or poor	CIF comp. median	Comp. % excel. or very good	Comp. % very poor or poor
Jan-13	-	-	-	-	-	-	-	4.7	95	0
Several semesters with no CIF data for these professors										
Jul-19	4.0	Mean: 3.70	59	11	-	-	-	-	-	-
Jan-20	3.4		43	19	-	-	-	-	-	-
Jul-20	4.8	Mean: 4.77	89	0	4.6	87	0	-	-	-
Jan-21	5.0		92	0	5.0	91	0	-	-	-
Jul-21	4.4		70	2	4.0	67	5	-	-	-
Jan-22	4.8		78	6	4.6	78	4	-	-	-
Jul-22	5.0		88	0	5.0	88	0	-	-	-
Jan-23	4.6		80	1	4.5	82	1	-	-	-
Jul-23	-	-	-	-	4.0	63	6	-	-	-
Jan-24	5.0	-	81	2	4.6	78	2	-	-	-

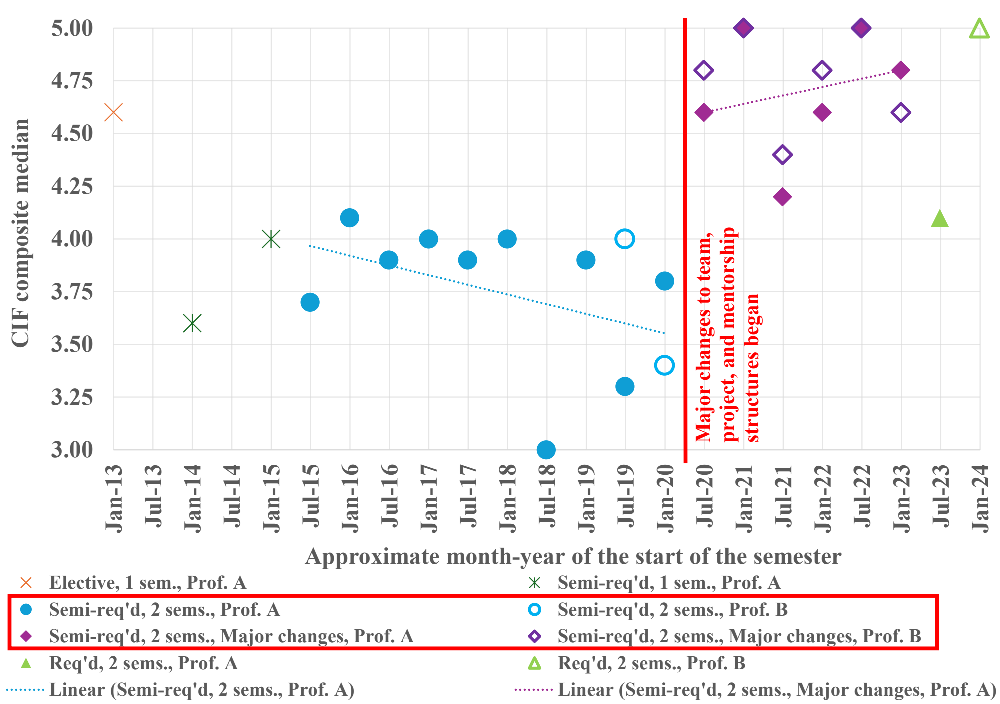

Figure 1. Student responses to CIFs regarding overall course experience

For purposes of reporting herein, the four co-authors of this paper were anonymized as Professors A, B, C, and D, with those letters not necessarily corresponding in order to the authorship sequencing. Professor A is the only professor who has co-taught the course continuously since its beginning in Spring 2013; hence, Professor A's CIF composite median scores are used in **Table 3** and shown with prominence in **Figure 1**. The other three co-authors represent the only other instructors for the course historically who both taught the course for at least one academic year and remain on the faculty at Notre Dame as of writing. Professor B also taught on both sides of the "major change" delineation, albeit in a comparatively lower number of years; thus, Professor B's CIF composite median scores are also included in **Figure 1**. CIF composite median scores for Professors B, C, and D are included in **Table 4** and validate that Professor A's composite median scores are generally representative for the group of instructors.

Instructor-led surveys were given at the end of each capstone course to evaluate a wide-range of items, including peer evaluations, career and graduate school plans, Fundamentals of Engineering (FE) exam status, and experience with mentors. The component of evaluating the students' experience with mentors was added to the survey starting at the end of AY 2021–22, was missed the following year due to instructor oversight, and then renewed in AY 2022-23. Students were asked to evaluate their mentors (as a team if they had multiple individuals mentoring them) on a scale of 5 to 1 in each of the four categories listed in **Table 5**, using the following scale: 5. Exceeds expectations, 4. Meets expectations, 3. Needs some improvement, 2. Generally unhelpful, and 1. Serious problem. The results are summarized in **Table 5**. Note the improvement between the two AYs measured, especially regarding lower 5th percentile and minimum scores, likely resulting from the limited but important culling of mentors who were not a good fit for the class as well as the experience gained by repeat mentors and faculty from preceding years. The sharing of strong examples of deliverables by previous classes with new classes appears to have also helped better calibrate the expectations of both students and mentors. The instructors also asked questions with open-ended responses and specifically for students to provide open-ended commentary pertaining to any category to which they assigned a score of 3 or less for questions limited to numerical responses.

Table 5. Student responses regarding their experience with their mentors

Approx. month-year of the start of the semester	Jan-22 (n = 54 responses)			Jan-23	Jan-24 (n = 54 responses)		
	Mean	Lower 5th percentile	Min.		Mean	Lower 5th percentile	Min.
Sponsor expectations and guidance regarding the scope of your final deliverables	**4.1**	**2.7**	**1**	**No data**	**4.4**	**3.0**	**2**
Timeliness and dependability	**4.2**	**1.7**	**1**		**4.7**	**3.7**	**3**
Communication	**4.4**	**2.7**	**2**		**4.8**	**4.0**	**3**
Overall sponsor recommendation	**4.3**	**1.7**	**1**		**4.7**	**4.0**	**3**

Measuring the mentor experience

Since AY 2020–21, instructor-led surveys have been given to the mentors at the end of each academic semester as part of the formal student grade determination for the course, and also to evaluate the mentor experience with the students. The limited-response questions are grouped into two categories: Weekly meetings and deliverables. The questions asked of the mentors are listed in **Table 6**.

In regard to the weekly meetings, the mentors are asked to rate how the students as a group met each preparatory element for their meetings using the following scale: 5. Exceeds Expectations (did required effort plus more, took leadership on coordinating tasks and volunteering ideas for next steps), 4. Meets Expectations (did required effort with minimal to no pushing, but took minimal leadership for coordinating efforts and planning next steps), 3. Needs Some Improvement (did required effort but only with occasional pushing, took little to no leadership), 2. Generally Poor (needed to be pushed constantly to carry out delegated tasks, and provided poor, untimely, and low-quality deliverables for each meeting), 1. Serious Problem (even worse than "generally poor"). In regard to the end-of-semester deliverables, the mentors are asked to evaluate aspects of the deliverables and associated student efforts on an identical scale of 5 to 1 as with the evaluation of weekly meeting components.

The general trend apparent in the mean evaluation scores listed in **Table 6** is significant improvement in virtually all categories year-over-year between the first AY evaluated (i.e., the year in which major changes were initiated in the class) and the second AY evaluated, followed subsequently by a steady-to-slight downward trend year-over-year in many categories. The instructors can reliably assume that lessons learned by both the instructors and the mentors themselves in the first year in which major changes to the project and mentorship structures were initiated (i.e., AY 2020–21) provided useful precedents and recalibrations for subsequent years. The instructors do not yet have a strong hypothesis regarding the cause of the steady-to-slight downward trend of evaluation scores evident in subsequent years.

The instructors also asked questions with open-ended responses and specifically for mentors to provide open-ended commentary pertaining to any category to which they assigned a low score for questions limited to numerical responses. Mentors were also asked whether they wanted the level of faculty involvement in group meetings and mentorship to change, on the efforts of individual student team members, whether expectations for students or mentors should be recalibrated, what skills the students lacked most at the beginning of the project, and whether notable improvements in these skills were recognized by the mentors. The plurality of mentors consistently identifies construction document preparation (i.e., CAD/BIM drafting and detailing) skills as the biggest deficit in the students' preparation prior to the capstone course. At the end of each capstone course, mentors were also asked with open-ended responses whether they had made job offers to any students in the class and whether they would be agreeable to mentoring in future years. The majority of mentors responded positively to both of these latter questions, especially in regard to being willing to participate in future years, often with the stipulation that they can convince some of their own additional team members to assist in order to lessen the mentoring load on individuals in their team.

Table 6. Mentor responses regarding their experience with their student groups

Approx. month-year of the start of the semester	Jan-21	Jan-22	Jan-23	Jan-24
Number of responses, n (at least one per mentor, but sometimes multiple)	**16**	**19**	**13**	**23**
Weekly meetings	**Mean**	**Mean**	**Mean**	**Mean**
Clearly addressed progress made since previous meeting.	3.8	4.6	4.5	4.3
Clearly addressed how they quality controlled (QC'ed) their own work prior to asking for your review and/or consideration.	3.1	4.1	4.2	4.0
Clearly addressed what unknowns they faced and what educated assumptions they made to work through these unknowns.	3.6	4.4	4.7	4.4
In collaboration with you, clearly established goals to accomplish before their next meeting with you.	3.9	4.6	4.5	4.3
Ensured that every team member had an opportunity to update you on their individual activities.	3.8	4.6	4.7	4.5
Mean for all scores within this category	**3.7**	**4.5**	**4.5**	**4.3**
Deliverables and associated efforts	**Mean**	**Mean**	**Mean**	**Mean**
Technical Quality: Completeness, Accuracy, Technical Proficiency	3.5	4.4	4.2	4.0
Effort: Team members exhibited hard and efficient work; willing to learn material outside their comfort zone; fought through obstacles that may have otherwise weakened their deliverables	3.9	4.7	4.5	4.3
Documents: Proficiency in preparation of written documents and drawings (as applicable; Emphasis: would you be proud to submit this work as 90% complete to your clients?)	3.2	4.1	4.4	4.0
Timeliness: Expeditious completion of tasks throughout the semester to ensure that deliverables were not entirely compiled just in the final few weeks of the semester (i.e., did students ensure you saw progress was made on deliverables throughout the semester as appropriate to your project and workflow?)	3.6	4.2	4.5	4.1
Dependability: How much faith would you have in submitting some of the more unique details, etc. to your client (as 90% complete) knowing young engineers did the bulk of the work?	3.3	4.2	4.2	4.0
Creativity: Students were willing to look for innovative solutions and approaches within and outside your direct oversight	3.6	4.2	4.4	4.2
Communication: Somewhat redundant to the previous section, but comprehensively, did students come prepared to weekly meetings, provide timely information on progress/problems, and - most importantly - respect the limits of your time commitment?	3.9	4.6	4.5	4.4
Attitude: Were the students professional in their conduct, enthusiastic, cooperative, and patient?	3.9	4.9	4.8	4.8
Mean for all scores within this category	**3.6**	**4.4**	**4.4**	**4.2**

Measuring student-employment outcomes

One of the explicit goals of the capstone course is to improve student-employment outcomes to both the benefit of employers – specifically the employers who participate in the course as compensation for their volunteering contributions to the capstone – and to students by widening student career perceptions, improving their real-world skill-sets, and offering more extensive direct networking opportunities.

In regard to the networking opportunities, instructors set aside dedicated in-class time for external mentors to market themselves and their companies in the Fall semester each AY starting in AY 2021–22. These classes are marketed to the students as "Career Options Days." Most mentors participate in person, and the remainder participate virtually. Many of the mentors – especially the engineering design consultancies – have shared that they find these recruiting sessions to be more valuable to their hiring successes over the past few years versus more general career fairs hosted by the university given the more targeted relevant audiences in the course setting.

Two questions on the instructor-led surveys given to students at the end of each capstone pertain to whether the students have accepted employment with a capstone participant firm. The resulting proportional responses are summarized in **Table 7**. The question was made optional in the first two years of giving it, although the instructors suspect that most "no responses" were likely equivalent to "no." Note the general increase in students year-over-year who went to work for a participant firm, which was approximately 1-in-3 (i.e., 33%) students in the most recently completed academic year. The instructors do not have a particular goal for this proportion, other than to have it high enough that the capstone course is relevant to both students and participant firms but low enough to avoid "recruiting into a vacuum." Approximately 1-in-6 (i.e., 17%) students "met" their future employer in the capstone course in AY 2022–23.

Table 7. Student responses regarding their employers' participation in capstone

Approx. month-year of the start of the semester	**Jan-22**			**Jan-23**			**Jan-24**		
Number of responses + no responses, n	**54**			**36**			**54**		
Question / % Response	**Yes**	**No**	**No resp.**	**Yes**	**No**	**No resp.**	**Yes**	**No**	**No resp.**
Is your employer one of the firms that either sponsored [i.e., mentored] a project in this class or presented at our "Career Options Days" presentations in the Fall?	19%	74%	7%	25%	50%	25%	33%	67%	0%
Did you discover, meet, and/or develop a more formal connection with your employer initially through some activity or connection in this class?	11%	81%	7%	17%	58%	25%	13%	87%	0%

Another measured outcome of student-employment regards year-over-year changes to starting salaries. The benefit to students from higher starting salaries is self-evident. Furthermore, the instructors consider increases in starting salaries relative to market trends (i.e., normalized to be sector-specific inflation adjusted) to be a proxy for employer satisfaction with curriculum changes, improved networking opportunities, and student career skills enhancements made within Notre Dame at the college and department levels, including within the subject capstone course. Graduation numbers [19] and median starting salaries [20] for Notre Dame graduates in civil and environmental engineering, respectively, are listed in **Table 8**. Note that the environmental engineering major (i.e., a separate ABET-accredited degree within ND CEEES now distinct from civil engineering) was first made available to first and second-year undergraduates in AY 2013-14, resulting in the first environmental engineering majors graduating in AY 2015-16.

In order to determine whether median starting salaries for ND CEEES students were substantially improved by initiatives *within Notre Dame* versus external market factors between the subject periods of interest (i.e., five years preceding versus the three years after AY 2020-21), median starting salaries from ND civil and environmental engineering graduates were normalized by the mean starting salaries from the National Association of Colleges and Employers (NACE) [21] as shown in **Table 8** and **Figure 2**. While it would be preferred to take the ratio of median-to-median, note that the mean of the NACE data set is likely approximate to the median given that there were 5104 total civil engineering graduates with a knowledge rate of 67.7% for civil engineering and 684 graduates with a knowledge rate of 70.3% for environmental engineering for the Class of 2023. By taking the ratio of ND median to NACE mean, year-over-year changes in salaries due to nationwide markets trends (e.g., year-over-year sector-specific salary inflation) are normalized. As shown in **Table 8**, there is a practically and statistically significant increase in the salary ratios between the two time periods considered for both civil and environmental engineering salaries, respectively, indicating the significance of changes initiated within Notre Dame starting in AY 2020–21. Note that the variability (as indicated by the standard deviation, SD) for the salary ratios for environmental engineering majors is much higher than for civil engineering majors.

In order to determine whether median starting salaries for ND CEEES students were substantially improved by initiatives *within the ND CEEES department* versus other initiatives within Notre Dame between the subject periods of interest (i.e., five years preceding versus the three years after AY 2020-21), median starting salaries from all ND engineering graduates (i.e., across the entire College of Engineering) were normalized by the mean starting salaries from the NACE database for all engineering graduates as shown in the far right columns of **Table 8**. Note that there is virtually no practical nor statistically significant difference between the mean salary ratios in the time periods compared when the median starting salary for all ND engineering graduates is normalized by the mean starting salary for all NACE engineering graduates.

The resulting provisional conclusion is that the aforementioned improvements in starting salaries for ND civil engineering and environmental graduates for the period starting in AY 2020–21 normalized by NACE mean salaries cannot be due in large part to initiatives within Notre Dame but outside of the ND CEEES department (wherein civil and environmental engineering majors reside), because otherwise one would expect to see corresponding improvements in the normalized starting salaries for all ND engineering majors (i.e., any engineering career services initiatives at Notre Dame would be targeted to equally support all students within the college). Thus, career initiatives within the ND CEEES department starting in AY 2020–21 are likely the most substantial cause of the observed improvements in normalized starting salaries for ND civil (and possibly environmental) engineering majors. The most substantial career-focused initiatives in the ND CEEES department that were implemented during this time period were the aforementioned changes in the capstone course.

Table 8. Notre Dame (ND) engineering median starting salaries vs. NACE engineering mean starting salaries for normalizing ND salaries to account for sector-specific inflation adjustment

Approx. start of semester	ND Civil Engr.	ND Enviro. Engr.	ND All Engr.	NACE Civil Engineering			NACE Environmental Engineering			NACE All Engineering		
	Median salary	Median salary	Median salary	Mean salary	Normalized ND Civil / NACE Civil	Stats. ND Civil / NACE Civil between considered time periods	Mean salary	Normalized ND Enviro / NACE Enviro.	Stats. ND Enviro. / NACE Enviro. between considered time periods	Mean salary	Normalized ND Engr. / NACE Engr.	Stats. ND Engr. / NACE Engr. between considered time periods
Jan-14	$57,800	-	$65,000	$54,656	1.06	-	$56,469	-	-	$64,891	1.00	-
Jan-15	$60,000	-	$67,500	$57,368	1.05	-	Outlier removed	-	-	$63,764	1.06	-
Jan-16	$60,000	$55,000	$69,000	$57,091	1.05	Mean: 1.050 SD: 0.012	$58,508	0.94	Mean: 1.000 SD: 0.061	$64,981	1.06	Mean: 1.048 SD: 0.018
Jan-17	$60,000	$60,000	$69,100	$57,495	1.04		$56,785	1.06		$64,699	1.07	
Jan-18	$60,000	$63,000	$70,000	$57,965	1.04		$58,623	1.07		$66,638	1.05	
Jan-19	$63,000	$56,000	$72,000	$60,250	1.05		$58,732	0.95		$70,219	1.03	
Jan-20	$66,725	$61,000	$74,548	$62,249	1.07		$62,455	0.98		$72,115	1.03	
Jan-21	$67,250	$65,000	$76,000	$61,314	1.10	Mean: 1.093 SD: 0.006 **Mean diff.: +0.043**, *p*-value: 0.001, 95% CI [0.025 to 0.062]	$58,318	1.11	Mean: 1.093 SD: 0.029 **Mean diff.: +0.093**, *p*-value: 0.05, 95% CI [0.000, 0.188]	$71,516	1.06	Mean: 1.050 SD: 0.010 **Mean diff.: +0.002**, *p*-value: 0.87, 95% CI [-0.026, 0.030]
Jan-22	$71,000	$72,000	$79,000	$65,114	1.09		$64,741	1.11		$76,249	1.04	
Jan-23	$75,600	$70,000	$83,900	$69,106	1.09		$65,820	1.06		$80,085	1.05	

Note: Response rates available at the referenced database websites [20] and [21]

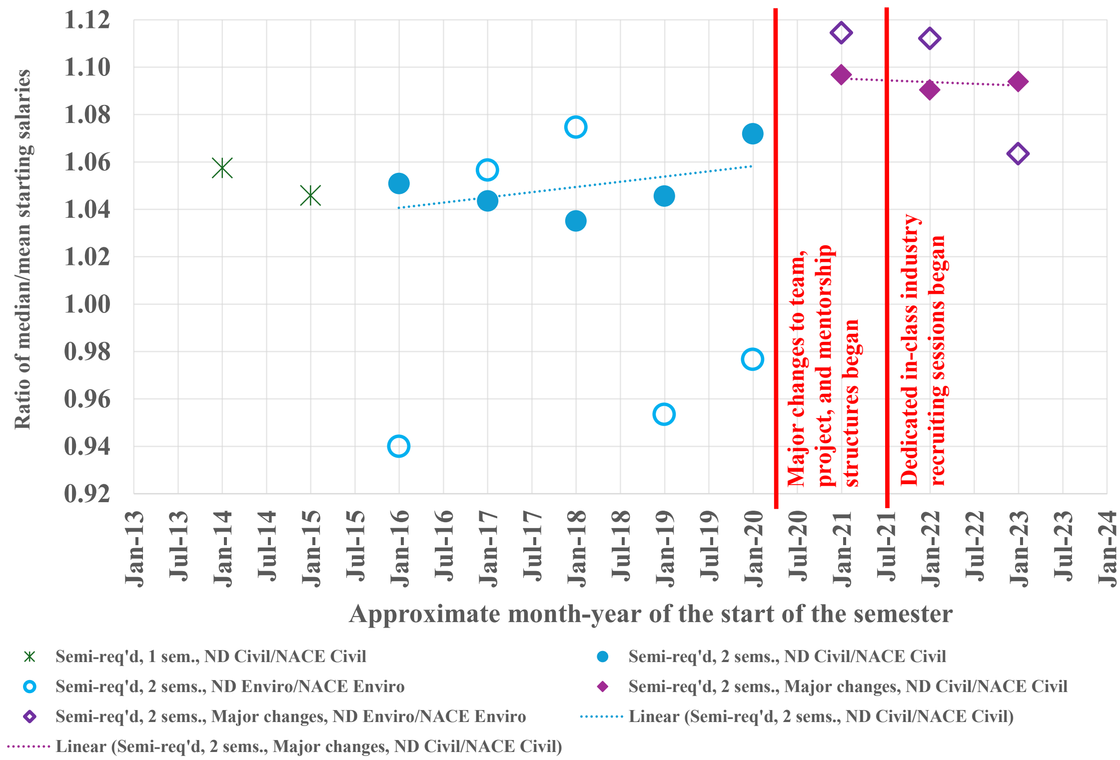

Figure 2. ND civil and enviro. engr. median salaries normalized for sector-specific inflation adjustment by NACE mean salaries

Summary and conclusions

Significant changes were implemented into the senior design capstone course for civil and environmental engineering students at the University of Notre Dame over the course of an eleven-year period from academic year (AY) 2012–2013 to AY 2023–24. The most significant changes began in AY 2020–21, wherein the instructors reduced group sizes and increased the number of external mentors involved in the class, enhanced final deliverable targets from schematic to permit-level construction documents, and implemented more frequent external mentor meetings. Other notable course changes in subsequent years included setting aside dedicated in-class time for external mentors to market themselves and their companies and adding general contractors (GCs) as external mentors to the course.

Measured outcomes from the changes in the senior capstone course include the following, when available:

- Student experience as measured via formal, anonymous, and University-administered course and instructor feedback (CIF) surveys and instructor-administered course-specific surveys;
- Mentor experience as measured via instructor-administered course-specific surveys; and

- Student and employer (i.e., "student-employment") experience as measured by instructor-administered course-specific surveys, specifically the proportion of students who ultimately accepted employment offers from mentors' companies, and reported starting salaries versus college, industry, and national trends.

Measured outcomes following the major changes to the course include the following:

- Improved student experience in CIF surveys in virtually all categories measured, including a 0.94-point increase in the CIF composite median on a scale of 1 to 5;
- Improved mentor experience in instructor-led surveys in virtually all categories between the first year after major changes and the second year, including a 0.8-point increase in the mean evaluations scores pertaining to both weekly meetings and end-of-semester deliverables on a scale of 1 to 5; and
- Improved student-employment experience based on increasing rates of students accepting positions with employers who participated in the senior capstone course, up to 33% in the most recently completed academic year; and
- Improved student-employment experience based on starting salaries with year-over-year increases that improved relative to salaries from previous ND civil and environmental engineering graduates, including a greater than 4% increase in normalized starting median salaries for ND civil engineering graduates and a greater than 9% increase in normalized starting median salaries for ND environmental engineering majors in the capstone following the implementation of major changes to the course, and also generally outpaced college, industry, and national trends.

References

[1] American Society for Engineering Education (ASEE) , "Civil Engineering Division 2025 Call for Papers," 2024. Available: https://nemo.asee.org/uploads_public/conferences/session_owner/call_for_papers_file/0000/3093/Call_for_Papers.pdf. [Accessed: Jan. 16, 2025]

[2] Accreditation Board for Engineering and Technology, Inc. (ABET), "ABET | ABET accreditation," *Abet.org*, 2019. Available: https://www.abet.org/. [Accessed: Jan. 16, 2025]

[3] PRISMA, "Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)," *www.prisma-statement.org*, 2020. Available: https://www.prisma-statement.org/. [Accessed: Feb. 15, 2025]

[4] American Society for Engineering Education (ASEE) , "ASEE PEER Document Repository," *peer.asee.org*. Available: https://peer.asee.org/. [Accessed: Feb. 15, 2025]

[5] Clarivate, "Clarivate," *access.clarivate.com*. Available: https://www.webofscience.com/. [Accessed: Feb. 15, 2025]

[6] C. Sarath and J. Kumar, "A Holistic Approach to Civil Engineering Capstone Design," 2024. Available: https://peer.asee.org/. [Accessed: Feb. 15, 2025]
[7] J. Norback, S. Howe, L. Riley, and P. Rhoad, "Student Reflections on Capstone Design: Experiences with Industry-Sponsored Projects Student Reflections on Capstone Design: Experiences with Industry-Sponsored Projects," 2014. Available: https://scholarworks.smith.edu/egr_facpubs/4/. [Accessed: Feb. 15, 2025]
[8] A. Leonard, G. Guanes, and E. Dringenberg, "Undergraduate students' beliefs about diverse approaches to making engineering design decisions: Exploring change during a capstone course," *International Journal of Technology and Design Education*, vol. 33, no. 5, pp. 1959–1989, Jan. 2023, doi: https://doi.org/10.1007/s10798-022-09802-w
[9] T. Muir, "The Optimal Group Size For Student Groups," *www.trevormuir.com*, May 05, 2022. Available: https://www.trevormuir.com/blog/optimal-student-group-size. [Accessed: Jan. 16, 2025]
[10] P. R. Laughlin, E. C. Hatch, J. S. Silver, and L. Boh, "Groups perform better than the best individuals on letters-to-numbers problems: Effects of group size.," *Journal of Personality and Social Psychology*, vol. 90, no. 4, pp. 644–651, 2006, doi: https://doi.org/10.1037/0022-3514.90.4.644
[11] J. Retherford, L. Beth, Hartmann, and B. Hartmann, "Civil Engineering Capstone Inventory: Standards of Practice & The ASCE Body of Knowledge," 2020. Available: https://peer.asee.org/. [Accessed: Feb. 15, 2025]
[12] H. Jackson, K. Tarhini, C. Fleischmann, N. Rumsey, and S. Zelmanowitz, "Session S3H Washington, DC 40 th ASEE/IEEE Frontiers in Education Conference Work in Progress - Selection and Execution of Civil Engineering Capstone Design Projects at the United States Coast Guard Academy," 2010.
[13] T. Jeffrey, P. Huffman, and J. Huffman, "A Real World Design Project in a One Semester Civil Engineering Capstone Design Course," 2014. Available: https://peer.asee.org/. [Accessed: Feb. 15, 2025]
[14] M. William, P. Manion, and J. Hakola, "AC 2012-3868: CIVIL ENGINEERING CAPSTONE CONSULTANTS: FROM RFP TO REALITY Civil Engineering Capstone Consultants: from RFP to Reality," 2012. Available: https://peer.asee.org/. [Accessed: Feb. 15, 2025]

[15] A. Bettencourt-Mccarthy, “Work In Progress -Building Empathy without Community Partners,” 2024. Available: https://peer.asee.org/. [Accessed: Feb. 15, 2025]
[16] S. Howe, L. Rosenbauer, S. Poulos, Poulos, and Sophia, “The 2015 Capstone Design Survey Results: Current Practices and Changes over Time Recommended Citation The 2015 Capstone Design Survey Results: Current Practices and Changes over Time*,” 2017. Available: https://scholarworks.smith.edu/egr_facpubs. [Accessed: Feb. 15, 2025]
[17] S. Howe *et al.*, “Preliminary Results from a Study Investigating the Transition from Capstone Design to Industry,” 2018. Available: https://scholarworks.smith.edu/egr_facpubs/56/. [Accessed: Feb. 15, 2025]
[18] M. Soller, “AC 2007-286: INNOVATIVE METRICS FOR ASSESSMENT OF A CAPSTONE COURSE IN A CONSTRUCTION MANAGEMENT CURRICULUM,” 2007. Available: https://peer.asee.org/. [Accessed: Feb. 15, 2025]
[19] “Accreditation - ABET - Civil and Environmental Engineering and Earth Sciences,” *Civil and Environmental Engineering and Earth Sciences*, Jan. 15, 2025. Available: https://ceees.nd.edu/undergraduate/program-outcomes-and-performance-criteria/. [Accessed: Jan. 16, 2025]
[20] C. Web, “Stats and Outcomes,” *Undergraduate Career Services*, 2021. Available: https://undergradcareers.nd.edu/getting-started/stats-and-outcomes/. [Accessed: Jan. 16, 2025]
[21] “First-Destination Survey,” *Naceweb.org*, 2018. Available: https://www.naceweb.org/job-market/graduate-outcomes/first-destination/. [Accessed: Jan. 16, 2025]