Benchmarking Architectural Engineering Capstones

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Abstract

Architectural Engineering programs that create students capable of being professionals and leaders in the AEC industry are in high demand regionally, nationally and internationally. From a global perspective, AE programs are unique and sparse compared to civil engineering and architecture programs. In total there are 22 ABET accredited AE programs in the United States that offer degrees. These programs must be adaptable to the industry to remain current with, and ahead of, leading industry practices. To remain most relevant to industry, AE programs regularly evolve their senior capstone project experience. Since the building industry is so diverse, and the AE programs themselves are often diverse from one another, the composition of capstone courses across programs has not been heavily studied in looking for critical trends. Thus, a benchmarking study is being undertaken to compare the 22 programs from a capstone standpoint. Trends in each program's capstone experience will be discussed and compared looking for similar and unique practices that other AE programs might be interested in as they further evolve their own offerings.

Introduction

Senior capstone design courses are the culminations of most, if not all, accredited undergraduate engineering programs in an attempt to provide an authentic engineering design experience [13]. Individual and/or team based capstones provide a comprehensive evaluation of a student's education [18]. A hallmark of an AE degree program at any university is the senior capstone project experience [25], which have been established in part as the positive result of industry pressure and ABET requirements [10]. Capstones allow upper-division students to showcase their knowledge in a practical way, often through developing design and/or construction projects similar to those experienced in an AEC firm.

Presently, there are 22 ABET accredited Architectural Engineering programs in the United States. These programs can be very different in their course structure and focus, but they all share the goal of providing excellent undergraduate education for their students [25, 30]. Besides program differences, studies of engineering capstones have revealed much variation in terms of course duration, project sources, project funding, faculty involvement, and team assignments [31]. This paper sought to benchmark different unique aspects that the 22 ABET accredited programs adopt for their capstone courses, and instead of breaking the discussion down by school, this paper will discuss trends in critical areas related to capstones. While each program is unique in its faculty makeup, its core curriculum, and it's culminating senior capstone experience, the goal is to produce Architectural Engineers for the future of the building industry.

A Need for Capstone Courses

Senior capstone design courses are defining learning experiences [16] that are culminations of most, if not all, accredited engineering programs in an effort to deliver an authentic engineering design experience [11, 13, 30]. As perhaps an AE curriculum's most visible attribute to students [8], capstone design courses deserve a renewed sense of importance as students strive to conclude the academic experience and prepare themselves for transition to professional practice [10, 20, 28]. It is an ABET accreditation requirement within AE Programs that graduates have a synthesis level of knowledge in one of the four traditional AE disciplines (HVAC, Lighting/electrical, Construction, or Structural), with appropriate levels of application and comprehension of the other three disciplines [30]. Capstones provide excellent mechanisms for developing new leaders amongst the cohort of graduating students in these areas [26,30].

Many researchers such as Dutson et al. [12]; Labossière and Roy [21]; and Todd et al. [32] have revealed that there is significant variation of capstone course delivery including but not limited to: course duration, project scope, project source, project funding, faculty involvement, team assignments, mix of specialties/disciplines, number of participants, and evaluation process. Important aspects in developing new or enhancing current capstones need to include:

- Active learning that support developing new and applying existing knowledge [31]
- Amount / type of involvement of professionals and experts with relevant design experience
- Length of the course (one or two semesters) to allow for detailed investigations [32]
- Number of faculty involved who have significant engineering design experience
- Available resources such as computer labs equipped with a full suite of modern design application software [31]

For more than a decade now, reports from industry and government have called for engineering students to be prepared for leadership roles [3]. In the late 2000's ASCE established a vision for the future that frames five critical learning outcomes [4,29]: (1) master builders, (2) stewards of natural environment, (3) innovators and integrators of ideas and technology, (4) managers of risk and uncertainty, and (5) leaders in shaping public policy. Based on this vision, there have been renewed studies in the last 10 years on capstones to meet current demands. Studies have included:

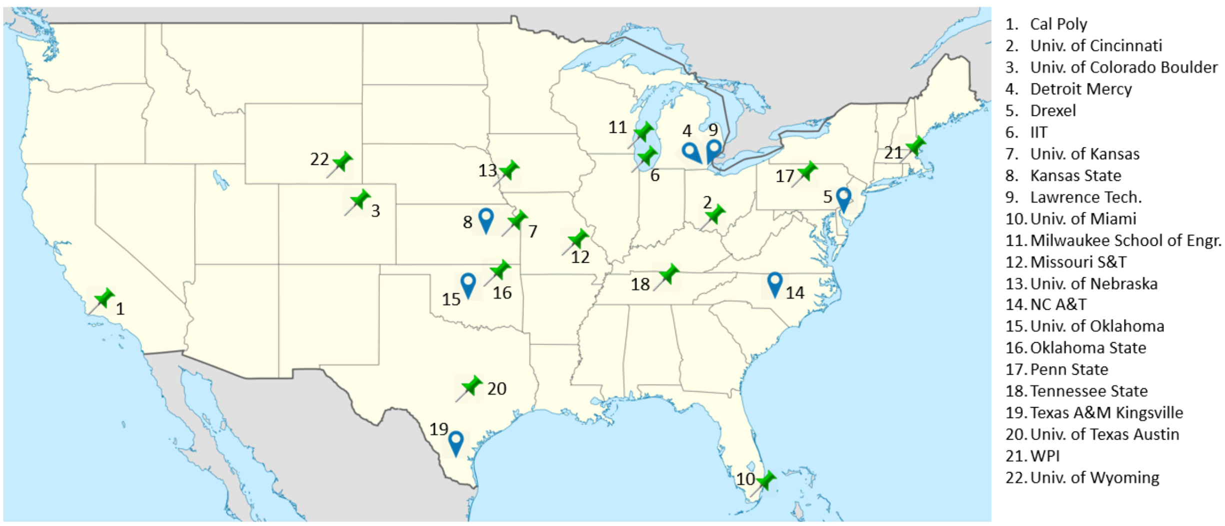
- Engineering ethics [24]
- Leadership skills [3]
- Integrating technology (for course admin administration and student usage) [30]
- Service-learning and community-based projects [15]
- Multidisciplinary projects [19]
- Design teams assembled from different majors or emphasis areas within a major [34]
- Principles of sustainability [6]
- Developing projects that are more user centered in focus [14]
- Treating the process as a simulated industry request for proposals (RFP) [5]
- Emphasizing hands-on, open-ended problem solving [17]

It became apparent in the initial research for this study that there are significant differences between each of the 22 ABET accredited Architectural Engineering programs in the United States, and that these differences would undoubtedly extend into the structure and format of the capstone.

Established Survey

A survey questionnaire was established to send to the 22 accredited AE programs to gather the information presented in this paper, and it was sent to contacts that had been previously determined as being directly or closely associated with the capstone course. The survey, performed using the Qualtrics™ survey system, consisted of 59 questions, though answers to all 59 questions were not required as the survey was broken into how the capstone was formatted (i.e., team, individual, or hybrid of both) and the survey taker was directed accordingly through the questions. Format of questions included multiple choice, multiple selection, and short answer questions, and the opportunity to share additional information (such as syllabi) with the researchers.

Of the 22 AE programs, all were invited to participate and were given two reminders over a two month period. The individuals who took the survey were all the designated instructors or coordinators of the capstone. At the time of data analysis, 15 out of 22 programs completed the survey. Of these 15, 11 fully completed survey with another 4 partially completing the survey (45-90% finished). For completeness, partial survey responses were included in this paper which gives way to the different sample sizes in different sections throughout. Figure 1 indicates the location of all ABET accredited AE programs in the U.S. and also shows which schools completed the survey (shown with different indicators). Of the respondents, 80% (n= 12) were from 4-year AE programs while 20% (n= 3) were from 5-year programs. Two of the programs have both 4 and 5-year program options for students, and four programs have integrated Bachelor/Master Degrees.



Note: Blue Marker indicates an AE programs, and Green Pin indicates AE programs that responded to survey

Figure 1: ABET accredited AE programs in the United States

Curriculum Placement of the Capstone

Capstone courses are meant to showcase a student's accumulation of knowledge and application of this knowledge to a design project. To accomplish this, almost every program has their capstone course occurring within a single year in the curriculum, either in a single semester or over two consecutive semesters. In surveying the programs, we asked where their capstone was located within the curriculum and its length. All 15 programs place their capstone in the final year of the curriculum, with 46.7% (n=7) occurring in the last semester (Spring / Quarter 3), 46.7% (n=7) occurring over the full academic year consisting of either multi-sequenced courses or as a single multi-semester course. 6.6% (n=1) said students can choose either a fall or spring semester (offered both semesters) but they only take the capstone for one semester. Out of 13 respondents, four programs have multiple semester capstones that are 30 weeks long (15 each semester), one program is based on 27 weeks (15 weeks in the fall and 12 in the spring), and one is based on 22 weeks (breakdown not indicated). For the 4-year programs, the durations for the capstone are between 14 and 30 weeks with four being 22-30 weeks long. For the two 5-year programs, one is

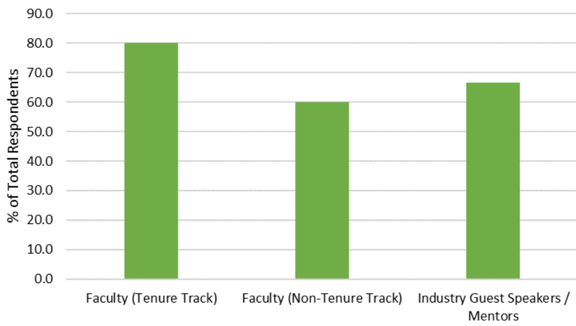
15 weeks long and the other is 30 weeks. For single semester capstones, three programs are 15 weeks long, two are 16 weeks, and one is 14 weeks in duration. For team projects, 42.8% of the programs have a 22-30 week long project. The majority of these single semester capstones (85.7%, n =6) are in 4-year programs with the remainder being in a 5-year program (n=1). In looking at duration based on formulation, all individual capstones are 2 semesters but the team capstones are spread amongst single (61.5%) and double semesters (38.5%).

Since AE programs are unique with design studios, the programs were asked if their capstone integrates with or concurrently works alongside an architecture studio. 28.5% said their capstone integrates work concurrently while 71.5% does not. Building upon that question, it was asked if the capstone directly builds upon an architecture design studio results. Here, 15% said it does, 85% does not but of those that do not, 38% have or would possible consider if the scenarios were appropriate. In reviewing the reasons why studios are integrated, the results show several trends. One 4-year program offers capstone concurrent to studio and two 5-year programs treat studio and capstone as the same course with no distinction. These programs indicated that they are taught by AE faculty or a combination of AE and architecture faculty. Multiple programs (50%), have indicated that to take their capstone course, a studio course has to be a pre-requisite or taken concurrently so that architectural knowledge can be utilized. As such, these courses are earlier and were recorded to be in the first to third or fourth year. Two schools (one 4-year and one 5-year) do not integrate in that they do not have a specific architectural program (on campus) with which to collaborate. Two schools (both 4-year programs), encourage but do not require students to select their project using a project designed by either an architectural student or from their prior architectural class, and in these programs 20-40% of the students select this option. Several respondents indicated their departments either tried unsuccessfully or had decided to not attempt to collaborate due to complex and challenging logistics.

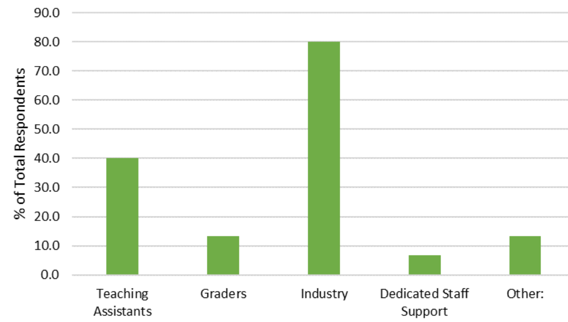
Who Teaches the Capstones

In regards to teaching in capstone courses, the type of instructor(s) assigned to the program can vary greatly. Figure 2a shows that there is a variety to the format used to teach capstones across the AE Programs. Teaching in the capstone can be accomplished by tenure track faculty, non-tenure track faculty, or industry mentors, or by utilizing a combination of those along with guest speakers to supplement specific technical skills related to projects. Each program surveyed could select multiple answers for the questions posed in both Figures 2a and 2b. 80% of the respondents said they have some tenure track faculty teaching while 60% of the programs also or alternatively employ non-tenure track instructors for their capstones. 67% of the programs indicated that the course also utilized some form of industry for an instructional teaching role.

It is common to have support beyond the course instructor(s) such as teaching assistants, graders, industry professionals, and/or dedicated staff. Figure 2b shows that industry provides supplementary support to capstone courses in 80% of the programs, with graders and teaching assistants also utilized in 14 - 40% of the courses. The “Other” category indicated in Figure 2b includes those AE programs that utilize lecturers from outside the program.



a) Who Teaches in the Capstone



b) Course Support in the Capstone

Figure 2: Faculty and Support Personnel in the Capstone

Another survey question centered on the number of faculty assigned to teach in the capstone.As shown in Figure 3, it is common to have multiple faculty assigned to teach. Results of the survey indicated two sets of numbers: 1) the number of lead faculty and 2) the total number of faculty involved. Lead Faculty are defined as the coordinators assigned to oversee the capstone. 80% of the respondents indicated that either 2-3 lead faculty (40%) or 4-5 lead faculty are involved (40%) in the capstone. While lead faculty are fully responsible for the capstone, approximately 60% of respondents indicated that there are additional faculty assigned to advise, mentor, and/or provide supplemental support as needed or requested.

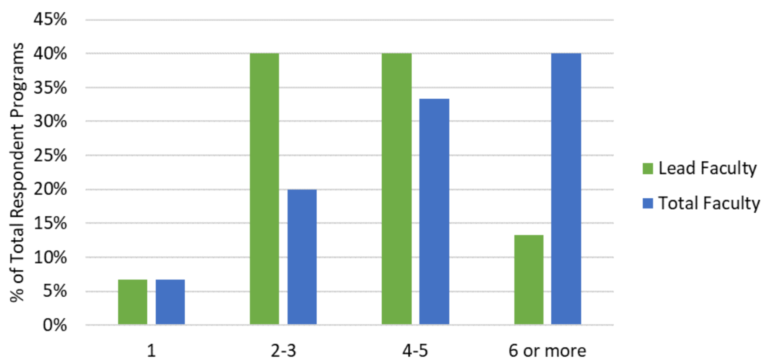


Figure 3: Number of Assigned Faculty in the Capstone

The results show that programs appear to devote multiple teaching faculty to the capstone which should be expected as this is the culmination of a student's educational experience in an AE program. In looking at faculty extremes, there was one program who had a sole teacher assigned to teach the capstone, and two programs who had all faculty assigned teach (with 15 or more faculty). One program indicated the number of faculty assigned to a course is dependent on the number of students in the course, with each faculty assigned no more than 8 students to advise.

In the survey, it was asked if the same faculty teach the capstone every year or if it changes. It became very apparent that the majority of programs surveyed (92%, n=13) have the same faculty assigned to teach in the capstone course on a permanent basis whereas 8% (n=1) rotate. Of the 92%, 4 programs have a core set of 1-4 faculty who are always assigned to teach in the capstone with an additional 2-10 extra faculty for supportive functions such as reviewers, advisors, judges, or jury members. Three programs say that rotating would be done if there were enough resources and/or interest that currently does not exist. Many of the core instructors have significant teaching experience and/or industry experience (15+ years), and about 25% of these faculty have appointments that are teaching focused instead of researched focused. 92% of the respondents indicated that there is a fair/equal representation of faculty by disciplines assigned to the capstone either formally or informally through consulting. This is a positive statistic in that not having an equal representation could be seen as having bias towards disciplines from a student perspective.

As literature promotes industry involvement, the survey asked those programs that include industry to rank their level of participation in four categories, including lectures, project support, course jurors, and student consultations / mentors. Ranking of their participation was based on the amount of interaction in the course and is shown in Figure 4. The results indicate that for those programs that include industry involvement, there exists a significant amount of collaboration with the students involved in the capstone course. In the four categories of participation, the "A Lot" and "A Moderate Amount" for all four categories was between 11.1% to 62.5%. Lecturing was the lowest and is not surprising as many from industry do not typically lecture but rather advise from their experience. Of the four categories, project support had the highest levels showing that AE programs connect heavily with industry on their projects.

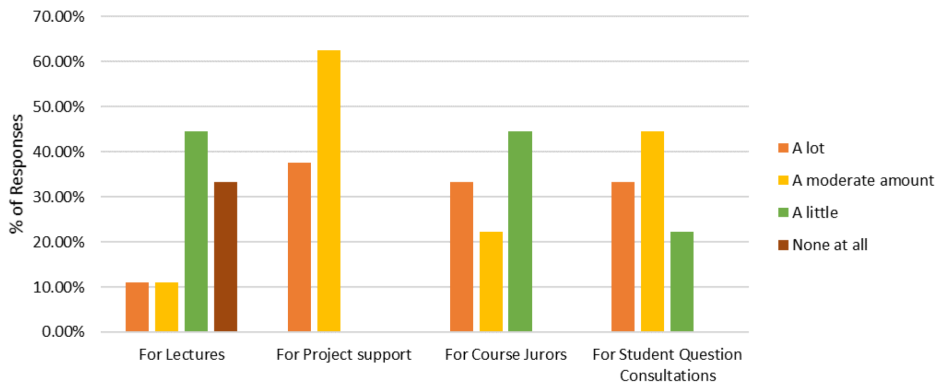


Figure 4: Industry Involvement in the Capstone

When the AE programs were asked about the roles industry members contributed, a variety of responses were generated. Here, 80% of the programs (n=12) have industry participate in mentorship / advising roles where they assigned to specific students/teams or are generally available to mentor (students select from a list of mentors as needed). Most mentoring happens periodically to provide feedback and advice on projects. Programs assigning mentors to students may use industry specific roles such as primary and secondary mentors in each of the following expertise: architecture, electrical, structural, mechanical, and construction. Programs with open resources break mentors into categories to allow for easier selection. Most programs with mentors also bring in specialty mentors (acoustics, facades, etc.) serving all students based on specifics for a given project. In addition to mentoring, other industry professionals are invited to supplement faculty expertise on projects. Industry often provides services to capstone courses, which can include:

- Oversight on proper capstone project selection
- Guest critics to the design process and calculation reviews
- Providing the projects and data used for a capstone course
- Evaluators / jurors of student work, presentations and documentations
- Financial support for the course

Given these roles, the AE programs were asked how they select their industry involvement members. All programs indicated that they must be a professional that practices within one of the Architectural Engineering disciplines or a specialty building area. Critical in selecting these firms/ individuals are: relationship with the department (sponsor, alumni, etc.); willingness to serve; experience with interdisciplinary collaboration, available time to consult, technical focus area, local to the university, and the project clients. About half of the respondents prefer their industry contacts to be local so that students can connect in person. The rest include members of industry from around the country, utilizing technology to allow more professionals to be involved.

Approximately 1/3rd of the respondents indicated that faculty selects participants who they want as mentors from lists of professionals. Two programs utilize large pools where students select mentors but the faculty / department controls who is in that pool, and other programs allow students to self-select mentors based on prior backgrounds and experiences with them such as internships.

Teaching Style and Content in Capstones

Some capstones directly teach new technical knowledge, with this being common in most engineering capstones within the U.S., while others are purely application of prior knowledge [33]. In many instances, faculty members are responsive to teaching topics in a "just-in-time" format. Other capstones teach a minimal amount of new material to students, relying instead on the knowledge students have gained throughout their educational career to be used in the course. The surveyed indicated the amount of teaching conducted in capstones, as shown in Figure 5. Faculty had the option to select from four categories that included:

- No formal teaching just advising on the application of prior knowledge
- Minimal formal teaching on just new topics necessary for the project
- Fair amount of new content due to content not being taught in another course
- Full course of new content due to content not being taught in another course

From survey results, two programs (15.4%) had *no formal teaching* of material, nine programs (69.2%) included *minimal formal teaching*, and two programs (15.4%) taught a *fair amount of new content*. No school responding to the survey indicated that they taught a *full course of new content*, which is understandable as a capstone should be the culmination of a student's educational career.

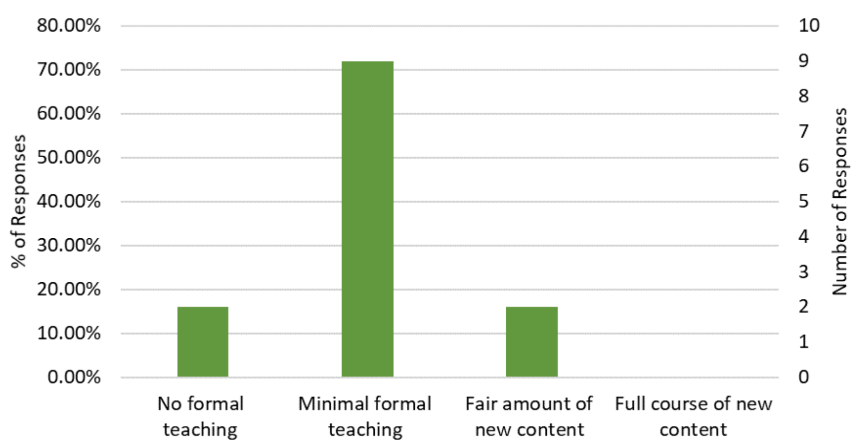


Figure 5: Amount of Teaching in the Capstone

If we look more closely at this data comparing 4-year vs. 5-year programs, two trends emerge. The first is that of the nine programs that includes *minimal formal teaching* in the capstone, eight are from 4-year programs. Second is that for those programs that teach a *fair amount of new content*, there is an equal 50% split between 4-year and 5-year programs. A more casual observer may feel that a 4-year program needs to educate its students more versus a 5-year program due to lacking a year of education, but this appears to not be the case. Similar statistics can be said about which type of program is teaching what amount of new content. 86.7% (n=13) of the survey respondents state that they teach specific content as necessary. 4-year programs do seem to focus more on teaching the building as a whole and integration compared to 5-year programs. Surprisingly, only four schools (26.7%) focus on how to work on teams, yet 86.7% (n=13) implement team projects, which might lead one to question if team work had been covered previously in the curriculum.

In view of extensiveness, capstones often require the acquisition of complementary technical expertise not covered in the most official curriculum [2]. Design knowledge can be taught considering processes and systems from multiple AE perspectives. These perspectives can include architectural design, systems design, standards and codes, computer technology, building performance and sustainability fundamentals, to name a few. Each of these add to and drive creativity and stimulate unsupervised learning by experience gained in the capstone. Because of the undertaking to simulate a realistic experience, industry participation in capstone courses is natural and encouraged. This combination of skills remains an area of study within engineering education that is still in need of further development and refinement for different majors [22].

Beyond technical skills, capstones are often an exercise in team dynamics, communication, and leadership beyond the technical aspects [31]. Here, the teaching of professional skills such as communication and project management takes on a more pivotal role [7]. It is important to realize that engagement is critical as learners do not often grasp and retain a concept until they can apply it as it applies to their designs. Engagement with course material requires students to apply class material by practicing relevant skill sets [23], something at which capstones excel [18]. The ability for faculty to coach students in effective collaborative behavior is also important [1,16].

Additional teaching beyond fundamentals is often necessary in capstones to enhance the student's educational experience, allowing the course to cover topics that will generate positive results for all involved. To understand the process better, programs were asked to provide information on additional topics they teach in the capstone. Answers to this question varied greatly, and included:

- Approach to a project design, including economic considerations, and software knowledge
- Presentations and writing best practices
- Architectural design and programming development
- Integration and collaboration with the various disciplines while working in teams
- Filling gaps on practical items (construction documents, etc.)
- Overview and or specific new calculations on items related to specifics of the projects, including but not limited to: Alternative energy integration, Fundamentals of acoustics, Long span structures, Enclosure design, Energy modeling, PT concrete, and Application of building codes.

Literature sources on teaching in capstones have placed varying levels of emphasis on different aspects of the design process and on how students generate technical solutions. Hand calculations vs computer simulations, larger process and integration, graphics, and soft skills can vary significantly. To see if there were trends in AE programs, the survey included questions on how much emphasis was placed on each of these categories. Figure 6 gives the survey results on the amount of emphasis placed on each of the categories, which the respondents indicating that each are emphasized either *a lot*, *a moderate amount*, *a little*, or *none at all*. The results indicate that much of the course content was emphasized for multiple topics, including design and graphics, presentation, the use of computers, and calculations related to the student's discipline of study. The *Processes of Design* area scored highest in the *a lot* emphasis with 61.5%, and a combination of *a lot* and *a moderate amount* combined for a total of 84.6%. The process of design area scored high in part because faculty and industry deem it important as a proper experience during the educational process. If constructed properly, the process of design can mimic what will be experienced in the profession upon graduation.

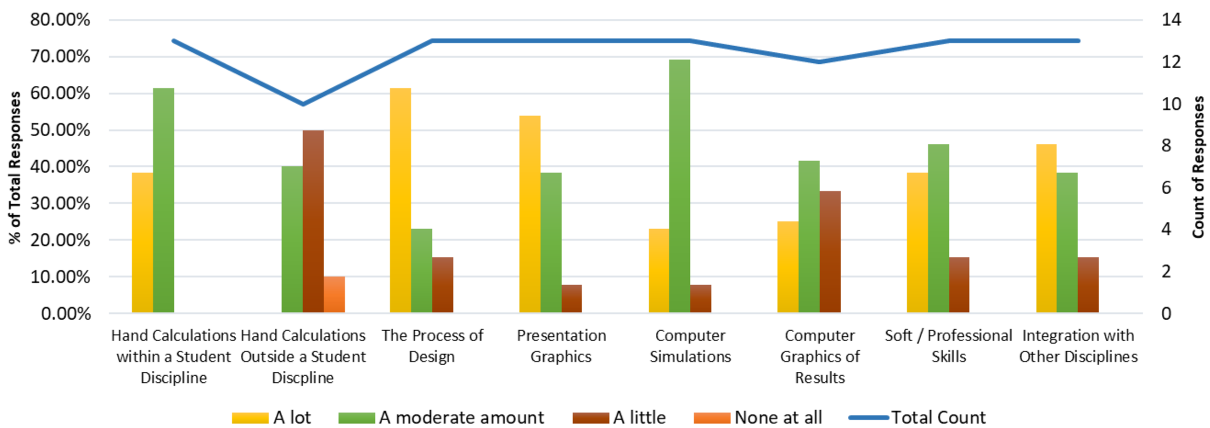


Figure 6: Documented Emphasis Levels of Critical Areas

The *Integration with Other Disciplines* area scored the about the same with *a lot* and *a moderate amount* combining for 84.6%, supporting the inclusion of interdisciplinary collaboration in the capstone. As computers are becoming more mainstream, capstones often implement them into the process. The respondents indicated that 92.3% (n=12) place *a lot* to *a moderate amount* of emphasis on the area of *Computer Simulations* with industry based software. In the area of *Presentation Graphics*, almost all of the programs (92.3%) indicated *a lot* or *a moderate amount* of emphasis being placed on the topic, realizing that the process of presenting a design solution is an important skill to possess. It is noteworthy to point out that while *Presentation Graphics* scored high in the amount of emphasis in a capstone, the area of *Computer Graphics of Results* did not have the same emphasis. The area of *Hand Calculations within a Student Discipline* are a vital part of a capstone with 100% (n=13) indicated *a lot* to *a moderate amount* of emphasis being placed on calculations. Lesser so is the area of *Hand Calculations outside a Student Discipline*, indicating that teams may be evaluated as a whole but that programs understand students performing design calculations outside their discipline should not be the of a capstone course.

Individual vs Team based Capstones

Capstones can be formatted to be taken on as individual student projects or can be assigned to be accomplished in teams which often are multi-discipline in nature. For individual formats, the project scope and size can become a concern as students may not have the time to focus on the important aspects of the project. The hours required for success in a capstone course can be difficult to complete for some students working individually. Additionally, the multidisciplinary nature of capstone projects can restrict the rigor for individual student projects in that the focus will likely need to be centered around a student's discipline studies without adding too much new material to be learned in the process of taking the course. This is not said as a judgement against individual projects as there are examples of highly successful capstone courses with this format.

Desjardins et al. [9] has indicated that with the growth of multi-disciplinary projects, where teams are assembled from different emphasis areas, the multi-disciplinary teams are able to tackle more comprehensive projects. Salas et al. [27] adds to this in that these multi-disciplinary teams promote integration that allow for more complex projects to be undertaken. Multi-disciplinary capstones, are often less than ideally constructed/executed due to relatively few faculty members having similar industry experience necessary to guide student teams through course projects. For some programs the inclusion of industry is used to offset this issue.

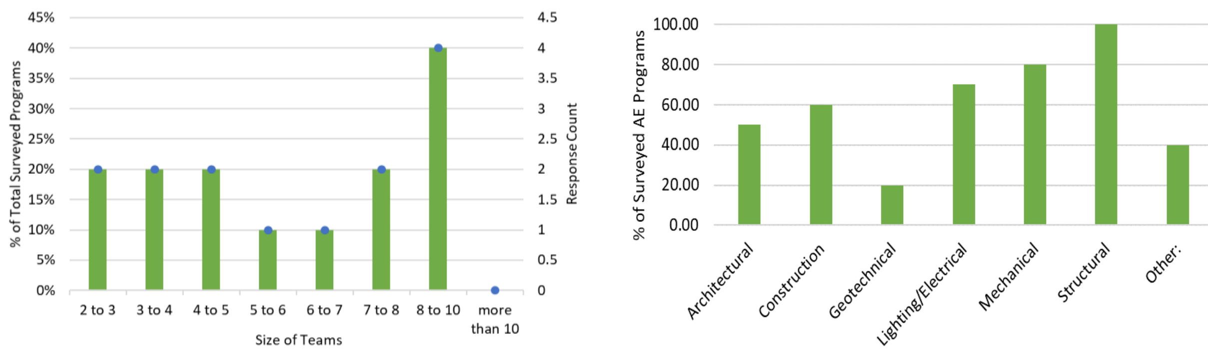
In review of the surveyed AE programs capstone courses, 86.7% (n=13) have team capstones, and 13.3% (n=2) have individual capstones. One of the schools within the individual count has two options, a team and an individual option where students can choose, with the individual being more popular. For those programs with team projects, how the teams are selected is a large area of discussion within literature with just as many studies showing self-selection vs random assignments working with similar success. The AE programs that offered team capstones indicated that 50% are chosen using faculty selection, 20% allow student self-selection of teams, and 30% implement a hybrid of student and faculty selection. Table 1 on the following page, lists survey comments pertaining to the reasons for the selection process chosen in programs.

Overall the justification for both self-selected and faculty selected teams have their places. The trends of each do overlap with the hybrid version allowing input by the student and the faculty. While 50% may be faculty selected, many of those programs do include input from students which could be ignored depending on other metrics like discipline balancing, knowledge of the students, project type, and anticipated outcomes for the project to help assure a positive result for all involved. Leadership balancing and discipline coordination on the team were popular with them reoccurring in 30% and 60% of the responses respectively. The one school that allows both team and individual only permits balanced teams of disciplines so that all focus areas are contributing equally. Two respondents indicated that student inclusion in this process can lead to better end results base on their perceptions of having their preferences matter.

Table 1: Team Composition Options for Adoption and Reasons

Faculty Selected	Self-Select	Hybrid
• Have a mix of disciplines and equal representation of the disciplines • Have a mix of leadership preferences and abilities • Ensure the best students are not on single team (balance GPA's) • University policy to randomly select	• In a yearlong capstone, large teams give more productivity • Stronger team dynamics which can lead to better performance • Typically works better when the students feel comfortable with who they are working • Select individuals who contribute and that they can access easily	• Students perceive better buy-in • Balancing of students • Students are asked for input into students they can and cannot work with on teams • Leadership preferences and design interests and try to distribute them accordingly

Knowing how teams are formed, the topic of team size is equally important to consider, with the survey data of team size indicated in Figure 7a. Teams made up of 8 to 10 students were the most popular with 40% of programs utilizing this team size. This size could allow for multiple AE disciplines to be involved on the same team, and also to allow for collaboration with students from outside an AE program. Additionally, there are several capstone competitions that allow for upwards of 10 team members and this is another reason for the large teams being popular (more discussed later on this aspect). Teams consisting of 2-3, 3-4, 4-5, and 7-8 students all had equal representation at 20% of the programs utilizing these team sizes. There is literature to suggest that while larger teams can cover more technical depth, smaller 3-5 person teams can often function more closely and better due to less conflict.



a) Student Size of Capstone Teams b) Disciplines included in Capstone Teams

Figure 7: Team Size and Team Discipline Compositions

Having looked at team formulation and size, discipline breakdown within teams was identified frequently. The breakdown of team disciplines obtained from the survey can be seen in Figure 7b, which indicates that *Structural* is the most common, with all teams (100%) including a student with a structural focus on the teams. Following structural, *Mechanical* is included on 80% of teams and *Lighting/Electrical* is included on 70%. These three number are to be expected as they are the most common disciplines that the surveyed AE programs educate in-house. Following on the mid-range side is *Construction* (60%) and *Architecture* (50%). *Geotechnical* is lowest with just two school deploying those options. This is not a surprisingly statistic since as some of the AE programs responding to the survey either are integrated with a Civil engineering department or allow outside majors to take the capstone. The *Other* category include disciplines such as: Fire protection, the civil disciplines of: Environmental, Water Resources, SWPPP, Transportation, and potentially students focused on specialty areas. Surprisingly high in the results is *Architecture*. What is not clear is if those students are real architectural student or if they are AE students who take that role.

As a follow up to the makeup of teams, programs were asked in more detail about the composition, particularly how many students of each discipline made up the teams. The commonly listed break downs are documented in Table 2 which is given on the next page. The results of this question varied greatly which should be expected due to the vast differences in the way AE programs set up their capstone courses, as discussed throughout this paper. Each program sets the size of capstone teams, allowing them to evaluate and use their program resources productively, and to morph the course as needed from year to year, considering factors such as number of students, faculty, and other resources that are available.

Table 2: Discipline Type and Quantity Formulation on Teams

Composition #	Breakdown	Frequency
1	1 to 2 environmental, 3 to 4 architectural and 4 to 5 are civil (all engineers).	1
2	2 Construction, 2 Structural, 2 Mechanical, 2 Electrical	2
3	2 Structural; 2 Mechanical; and 2 Construction	1
4	2 to 3 architecture majors with 1 architectural engineering (not discipline specified).	1
5	1 architectural (but an engineering student), 2 Structural, 1 Mechanical, 1 Electrical, 2 Construction, 1 Geotechnical	1
7	1 Construction, 1 Structural, 1 Mechanical, 1 Electrical	1
8	2 Construction, 2 Structural, 2 Mechanical, and 2 Electrical plus 2 extra on disciplines where the project is complex in those areas	2
9	Number and discipline vary based on students in each category but try to balance 4 disciplines first	1

Project Selection

Project selection is critical for the success of the capstone. Without proper project attributes, certain discipline requirements that relate to any and all required and potential analyses may not be realized, or worse, be feasible if the project is too simple, too difficult, or out of scope of the student's prior education. Figure 8 represents the collected information on how AE programs select projects and if they are team or individual focused. For Figure 8, it is important to know that the percentages are of the total programs that answered the question and schools might utilize more than one method. For team-based capstones, the data shows that 80% of the faculty select projects

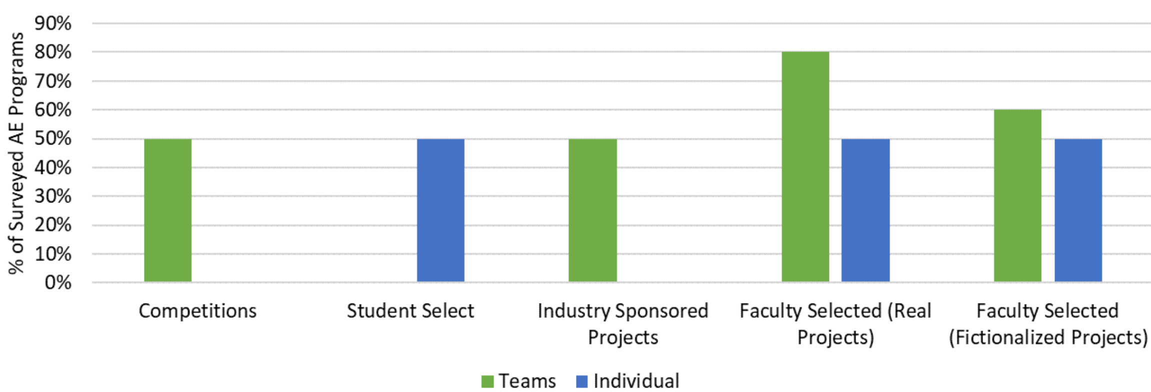


Figure 8: Selection Breakdown of Capstone Projects

and these are real projects whereas 60% of the faculty have adopted fictionalized projects. For individual project format, one of the two schools switch between real and fictional projects from year to year. Allowing the faculty to select the project is often ideal to achieve educational objectives for the course.

Utilizing design competitions was a common trend in which 50% of the programs participate. These allow students to get industry exposure if the project is real in nature but also permits them to highlight their abilities at a local or national level. The 50% indicated the following competitions in which they participate: AEI-SDC (more popular at 67%), Solar-Decathlon-Design, ASHRAE, IES, NAHB, and Net Zero. Allowing students to find their own project in which they have interest can allow the students to have 'buy in" to the project, however, only one program implemented this process. That program requires students to find a real building project (that cannot be shared with another student) that is either being designed or has been recently constructed. They find these projects through internships and from contacts at a career fair.

Recycling projects from year to year or mandating that projects be new each year is a common debate. With only a few exceptions, the majority of programs (76.9%) did not recycle projects from year to year. The 23.1% of those that do mentioned that this is not always done, but more as a measure if there are challenges in finding new projects (20% of the time they are recycled). In these cases they often keep the building but change client and requirements to force new solutions.

When selecting projects and/or competitions, faculty need to require sufficient complexity so that students can apply their skills developed from previous studies while still allowing for new exploration of knowledge. For competitions, faculty need to evaluate the appropriateness of the project and requirements to determine if that competition is acceptable. For student self-selection, guidelines need to be created for students to follow when selecting projects, which could include having students obtain proper owner permission if using real life projects or case studies. When it is up to the faculty, one respondent indicated that it can be a struggles to identify projects that provide sufficient breadth and depth of experiences but also provide variety for students interested in different aspects of the discipline. The criteria in Table 3 was captured in the survey on how projects are selected (for both team and individual).

Table 3: Criteria Implemented for Project Selection

Broader Criteria	Detailed Criteria
• Must have Civil, Architectural and Environmental components • Must be large enough for teams of 8-10 students so that there are "no slackers" • Sufficient level of interdisciplinary design components • Supportive clients and design professionals • Ability to exercise reasonable amount of design and freedom to select and integrate various solutions • Real project, ideally local for site visits but not necessary • Regional locations so that e, a real client though the building project is fictionalized • Must include all building systems	• Need supplied: soil borings, environmental studies, and other data site for the design • Complex site issues to resolve. • Medium size program 30,000 to 100,000 sf ideally. • Not involved in an active lawsuit • Specific systems within the project (Steel gravity frame or a DOAS system) • Min. # of Stories / total building height, must be under construction, rooms for creative lighting exploration

As mentioned earlier, some capstones offer the option to implement studio projects. Here, students create their own building in the Arch Studio prior to senior capstone. Then, teams select one of the members' project to develop after it has been approved by the faculty member(s). One program tries to utilize projects that have real local community request for some type of facility design.

Either concurrently or after selecting a project, the faculty may want to identify "challenges" or areas of interest that will help set the scope of the work for the course, or students may be allowed to define the scope of work, with faculty approval. It has been documented that if challenges presented to students are realistic, relevant to current issues and geographic location, and simulate common practices in industry, they receive the highest acceptance by students and industry supporters. Additionally, the more multi-disciplinary the challenge can be made, the more likely a design team (for team based capstones) are likely to accept and be excited about a project.

Student Workload / Formulation of Assignments

The creation of a capstone course needs to carefully consider the projected workload to allow students to have sufficient time to design, consider their results, and re-design as necessary. In addition, the workload of the capstone course must be considered relative to other concurrent courses which students are taking. It is easy for students to spend too much time on a capstone course and neglect their other courses or vice versa.

To understand how much of a workload capstones are in AE programs, Figure 9 documents two items that were surveyed relation to commitment: 1) The number of hours a student spends in-class per week for the capstone and, 2) The percentage of total credits the capstone for a semester or quarter. The data presented is based on the programs being 4-year or 5-year, and if the capstone is formatted as an individual or team project.

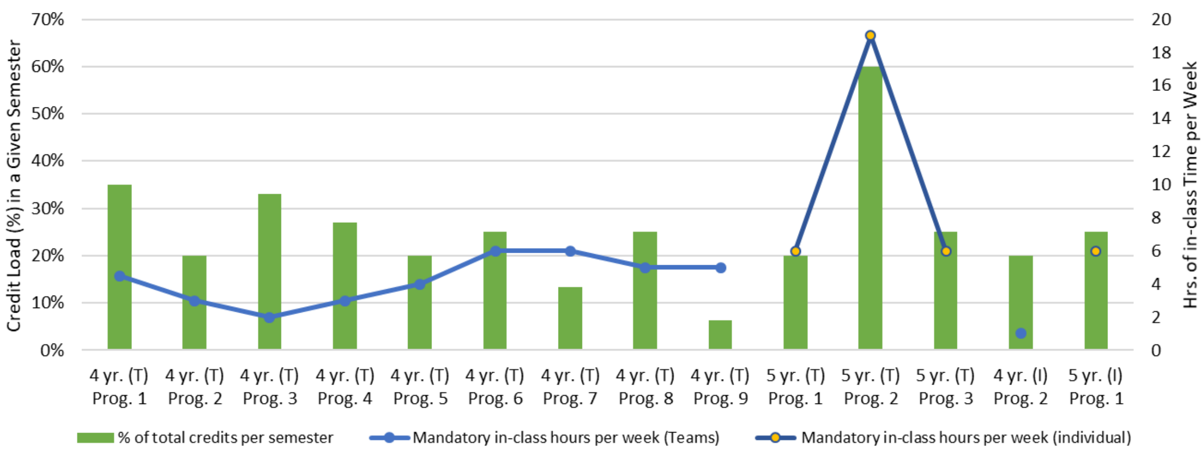


Figure Note: # yr. = # year in a program, (T) = Team Based, (I) = Individual Based, Prog. # = randomized AE Program Indicator (each gets its own bar)

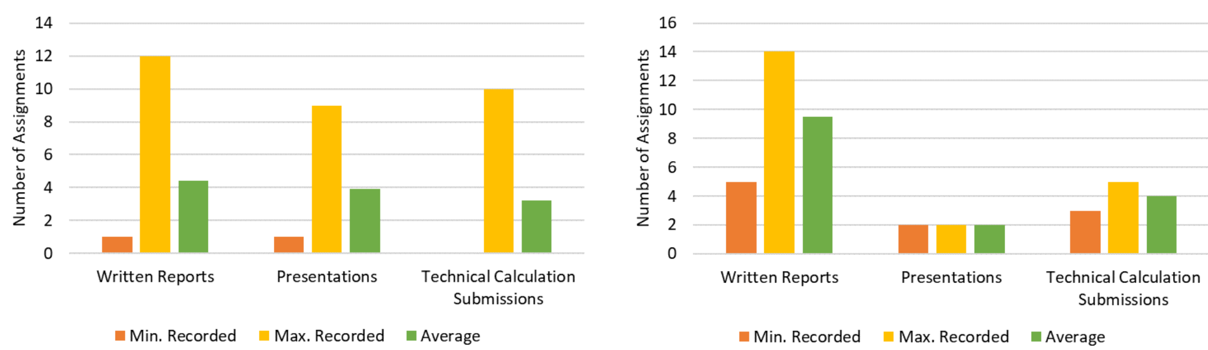
Figure 9: Statistics on Hrs. of class time per Week and % of total Semester Credits

In looking at Figure 9, there is a fairly consistent trend in the 4-year team configuration in regards to total course workload. The average percentage of credit load a 4-year team capstone encompasses is 22%. For 5-year teams, the trend varies significantly from 20 to 60% (mean is 35%). For individual projects, 4-year and 5-year programs (one of each) are similar with a mean of 23%. Capstones in the 4-year programs follow a similar trend for number of mandatory in-class hours per week. For 4-year teams, the mean here is 4.3 hours with a minimum of 2 hours and a maximum of 6 hours per week. Two of the three 5-year programs have similar mean in-class hours at 6 per week. The main outlier in the results is one of the 5-year team, identified as Program 2 in Figure 9. This school has their capstone set to account for 60% of the credit load for the semester, and a required class time of 19 hours per week. In discussions with this program, it was determined that the main activity for the final semester of this program is treated like a studio course, with 9 credit hours dedicated to the studio, and a 3 credit hour parallel course in project management. At the other end of the spectrum, one 4-year team program has their capstone be only 6% of credit load for the semester, with only 2 hours of class time per week. The recorded hours per week and percentage of credit load seems low and this questions needs to be followed up on with the program to make sure it was interpreted correctly.

Within the capstone course, student deliverables become important avenues to frame the learning experience. Based on capstone literature and the survey of programs there are different approaches that can be taken. Depending on the department requirements, faculty comfort level, and class support, the format of the capstone can be set to have numerous requirements, or be a more open-ended self-exploration. For capstone projects that are part of a building design competition, there are often stated project objectives and requirements that are technical yet broad to allow creativity, exploration into topics of interest, application of prior knowledge, and appropriate research on the topic. The following list details different possible formulation types, including:

- Specific deliverable requirements for exact topics
- Specific deliverable requirements for student selected areas of focus
- Open-ended assignments with exact topics
- Open-ended assignments with student selected areas of focus

The survey asked for the number of assignments in categories of *Written Reports*, *Presentations*, and *Technical Calculation Submissions*. Figure 10a and 10b gives the minimum, maximum and average that were recorded for the three assignment categories considering team (Figure 10a) or individual (Figure 10b) project formats. In looking at these three categories for teams, the lowest



a) Team Based Breakdown b) Individual Based Breakdown

Figure 10: Quantity of Assignments in Capstone Course

average was *Technical Calculation Submissions* for teams (mean=3.2) but for individuals it was *Presentations* (mean=3.9). The largest was *Written Reports* for teams (mean=4.4) and individuals (mean=9.5). A reason for technical calculation being low could be that these were incorporated into the written report instead of a separate submission. One respondent mention they had no formal submissions for calculation but they were reviewed regularly as they were continuously ongoing. The minimum number required for *Written Reports* was one in the team and five for individual while the maximum was twelve for team and fourteen for individual. The reason for the high numbers is not known but could be that smaller, weekly reports were required. An "other" category was also created to capture unique assessments, and for this category, responses indicated BIM models (one school), 2D Contract Documents and Specifications (two schools), and Posters (two schools) as being part of the requirements for the capstone.

The survey also asked if all disciplines required the same assignments during the capstone. From a team perspective, 60% (n=6) had different discipline requirements and for individual formats, 50% (n=1) had different requirements. For programs that do have different assignment based on the student's discipline, most commonly they are based on what the student contributes to the project and what is unique versus a common interest (i.e. BIM modeling vs structural calculations). One program indicated that for their individual capstone, since the disciplines integrate limitedly during the course, each discipline faculty set the requirements for the students based on the educational specialties, with shared common assignments to be completed by all in the capstone.

Student Work Assessment

The assessment approach in a capstone is often multi-faceted. A course is often formatted such that a standardized evaluation procedure can be formulated that allows for assessment of both technical and soft skills. Technical content and skills are both needed as capstones inherently encompass more than just mathematics for an engineering design to be successful. In surveying the AE programs, the following three main skill types for grading were established:

- Writing Skills
- Technical Skills
- Soft/Professional Skills (team dynamics, teamwork, presentation/speaking)

The survey asked for the percent breakdown of the overall grade which accounted for these three assessment areas, while also providing an option to incorporate an *Other* category. Minima's maxima's, and averages of all respondents are shown in Figure 11. The heaviest weighted assessment area is *Technical* with a range of 20 - 80% that gives way to a 52.8% average. The 20% was considerably lower than the rest with the next lowest being 40%. For *Writing* a range of 5 - 40% was dedicated to the course grade with a mean of 21.7%. When looking at *Soft/Professional* skills a range of 10 - 40% was found with a mean percentage of 20%. The non-technical side overall is weighed on average about equally. In the category of *Other*, one program identified that 10% of the course grade was assigned to student contributions to class. While fairly consistent, another program noted that each discipline has a potentially different weighting that then gets adjusted to account for group work.

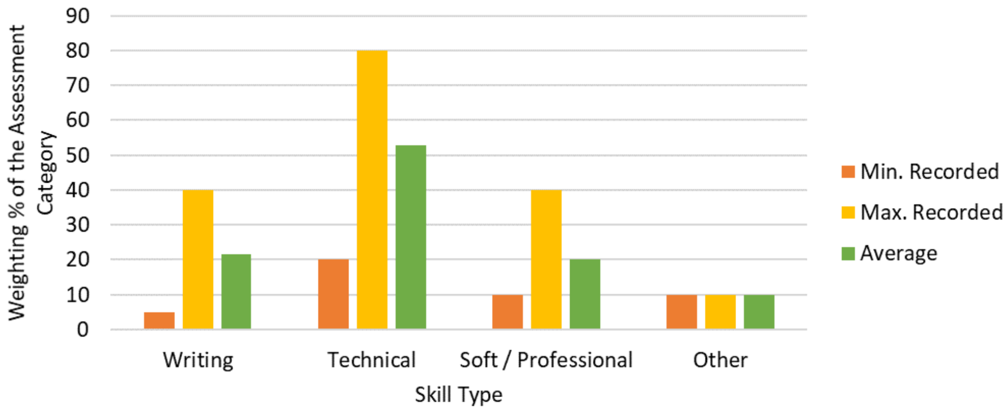


Figure 11: Weighting of Student Grades

With knowing the breakdown of assessment weighting, the mechanisms for grading are equally important. Table 4 breaks down the percentages for how *Mathematical, Presentations,* and *Written*

Reports of student work are graded. Note that for Table 4, respondents could select multiple responses in a given category if multiple mechanisms were used or are switched between for purposes of grading. For *Mathematical* calculations, the main assessment technique is through

Table 4: Grading Structure Mechanisms for Assignments: Team vs. Individual

Metrics	**Team-Based**		**Individual-Based**	
	%	**Count**	**%**	**Count**
Mathematical				
Overall all or nothing grading (0 or 100)	8.3%	1	25%	1
Partial credit based on predefined points with all or nothing (0 or 100 for each part)	8.3%	1	25%	1
Partial credit based on predefined points (point scale)	16.7%	2	25%	1
Predefined Rubrics with more generalized categories	66.7%	8	25%	1
Presentations				
Predefined Rubrics with more generalized categories	35%	7	50%	2
Partial credit based on predefined points (point scale)	15%	3	0%	0
By a single faculty	10%	2	0%	0
By a group of faculty (with averaging scores)	30%	6	25%	1
By a group of faculty (through discussing and forming a consensus grade)	10%	2	25%	1
Written Reports				
Numerical scale	38.5%	5	33.3%	1
Through discussing and forming a consensus grade	15.4%	2	33.3%	1
Predefined rubrics with performance scales	38.5%	5	33.3%	1
Ranking projects	0%	0	0%	0
By a group of faculty (with averaging scores)	7.7%	1	0 %	0

pre-defined rubrics with 66.7% for team and 25% for individual based capstones. This is interesting in that earlier technical courses typically assign points to specific calculations as compared to generalized grading, with one explanation being the volume of calculations that need to be graded. While rubrics were the highest, the other three methods were given at least one count. The other surprising statistic is that one program grades the calculations as a whole on the “it’s a 100% or a 0%”, the reason for this was not established during the survey.

Moving to professional skills, *Presentations* were surveyed for the 5 category options listed in Table 4. Predefined rubrics remain the top ranked response for team (35%) and individual (50%). The next highest is with a group of faculty averaging their grades (determined in various ways) at 30% for team and 25% for individual. What was not captured in the survey was if for those capstones that have multiple instructors and average grades, is the weighting equal between the instructor grades, or is more weighting given to those with more exposure to the students. The next professional skill asked was *Written Reports*. Here, programs were also asked on 5 category options. Numerical scales (that look at errors with specific points) and predefined rubrics with performance scales are equally used (38.5%) for team capstones. From the individual standpoint, numerical scales, predefined rubrics, and a census discussion were equally done (33.3%). A positive takeaway from this table for written reports, is that no faculty member/program ranks students against one another.

Conclusion

For this paper, a survey was sent to the 22 ABET accredited Architectural Engineering programs in the United States. Of the 22 programs, 15 responded either in part or entirely to the survey, and the results of the survey questions have been presented in this publication. Several conclusions can be drawn from this survey. First, with more than 1/3rd of the programs (7 out of 22) not responding to the survey, it would be to the advantage of this study to continue to contact those programs to encourage them to take part in the survey and to incorporate their responses into the results presented in this paper. Secondly, the question should be asked as to what to do with these results, and are they good to utilize for anything. It is the opinion of the authors that these results should be published on a larger database that could be used by all AE programs to research and review methods, techniques, and situations that other programs are using to educate their students. The information obtained from this survey can be used by AE programs to evaluate their current offerings and to look for trends in the education of Architectural Engineering students that could be of benefit.

An original goal of this paper was to establish a database, and discussions are underway for establishing such a resource of information available to all on the Architectural Engineering Institute (AEI) website. With this information available, we can better understand the strengths of each program which can be used to improve the education of all our students. Lastly, further research on this topic could be used to make the data from this survey better understood. The authors do concede that there is a lot of information presented in this paper that can use clarification, and this is due largely to the differences between the various AE programs and the way each has formatted their capstone courses. With respect to this clarification, a database of information could further explain the similarities and contrasts between the AE capstones, and allow programs to research new ideas that could be incorporated to enhance the educational experience of their students in the field of Architectural Engineering. Resources mentioned in this paper can help other new programs that are just starting their first set of cohorts or for schools considering developing new Architectural Engineering programs.

There are many similarities in the capstone areas mentioned in this paper, but there are also many differences. With four areas of focus in architectural engineering it seems evident that programs would differ as they build their curriculum on one of more of these areas. Having variety in the way capstones are formatted and on the topics covered in the course shows the strength of the architectural engineering capstones in that they provide impactful educational experiences for students as they prepare to transition into the profession.

Architectural Engineering programs compete with other engineering branches such as civil, construction, mechanical, and electrical engineering for students, and how we educate students in our programs have an effect on the profession, and on our success in the field of Architectural Engineering education. Capstone courses are the culmination of AE curriculums, and allow students to experience situations similar to those they will be exposed to upon graduation and entrance into the profession. The study performed for this paper of the current offerings in capstone courses will allow other programs to better understand the trends happening in current education, with the potential of increasing the educational opportunities within their own program.

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