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# How We Teach: Capstone Design

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# How We Teach: Capstone Design


## Abstract

Capstone design was the topic of the 2022 survey by AIChE's Education Division's Curriculum Survey Committee. This paper reports on the results from fifty-eight responses from institutions in the United States. Institutions are more likely to have a two- or three-course capstone design series than a single capstone course (68% to 27%) with a mean of 5.4 credit hours. Some institutions (20%) have design courses throughout the curriculum in addition to the capstone design sequence, but more programs (40%) have design projects within non-design courses throughout the curriculum. The course or courses in the capstone design sequence are primarily offered only once a year (78%) with a slight edge to the spring semester/winter quarter (80%) over the fall semester/quarter (72%). Most institutions (78%) include instruction in software or programming as part of the course(s). The culminating design project is most often a theoretical design (68%) as opposed to one based on experiments (3%) or resulting in a prototype (7%), and most institutions do not use the AIChE Design Competition problems (70%). Professional skills are mainly lightly covered with the exception of professional communication being covered in depth at 58% of institutions. At most institutions, capstone design is used to assess the extent of ABET outcome achievement for all seven outcomes except #6 (develop and conduct appropriate experimentation…).

Students typically complete only one culminating major design project (67%) in a team of 4.0 (mean) students. The mean of unique projects completed by the cohort is 8.6, but the mode is one project for the entire cohort (28% of institutions). Students receive formal feedback on their progress weekly at 50% of the institutions and every other week at 23% of institutions. The mode for weekly student time spent on projects is 6 – 10 hours per week (62% of institutions).

The mean size of a faculty team teaching capstone design is 2.8 faculty. Fifty-eight percent of the instructors have at least three years of industrial experience, and instructors are split nearly evenly between teaching-track and tenure-track. At least one capstone design instructor is a licensed professional engineer at 43% of the responding institutions. The faculty collaborate with industry at 65% of responding institutions.


## Introduction

The Curriculum Committee for AIChE's Education Division surveys departments about a topic each fall. These surveys allow faculty to benchmark themselves against other departments and gather ideas for changes to their courses. Repeating the surveys every decade lets the committee track changes in curriculum over time. The subject for 2022 was the capstone design experience, defined as containing "a culminating major engineering design experience which incorporates appropriate engineering standards and multiple constraints, and is based on the knowledge and skills acquired in earlier course work" (ABET 5.d). We included process, product, and plant design. This capstone design experience may be one or more courses. Capstone design survey results from 2012 have been presented previously in 2013 [1].

The survey itself is in Appendix A.  Emails were sent via the AIChE Chairs listserv to department heads, asking them to send the survey link to the appropriate faculty in their departments.  The survey link was also included in AIChE Education Division newsletters and ASEE Chemical Engineering Division newsletters and posted on social media.  Fifty-eight institutions responded and are listed in Appendix B.  Of those 58 institutions, 93% are on the semester system, and the others are on quarters.  Canadian institutions also responded, but their results will be presented at another conference in Fall 2023.

Faculty

Capstone design has special instructional needs.  The survey asked a series of questions about the faculty in general, the design faculty, how the design faculty spend their time, industrial collaborators, and other faculty-related course issues.  This section of the paper reports on capstone design from the faculty point of view.

One way of categorizing departments is by the faculty size.  The most common faculty size at the responding institutions was between 9 and 14.  The size distribution for all responding institutions is given in Figure 1.  The mean faculty size was 18, and the median size was 16.

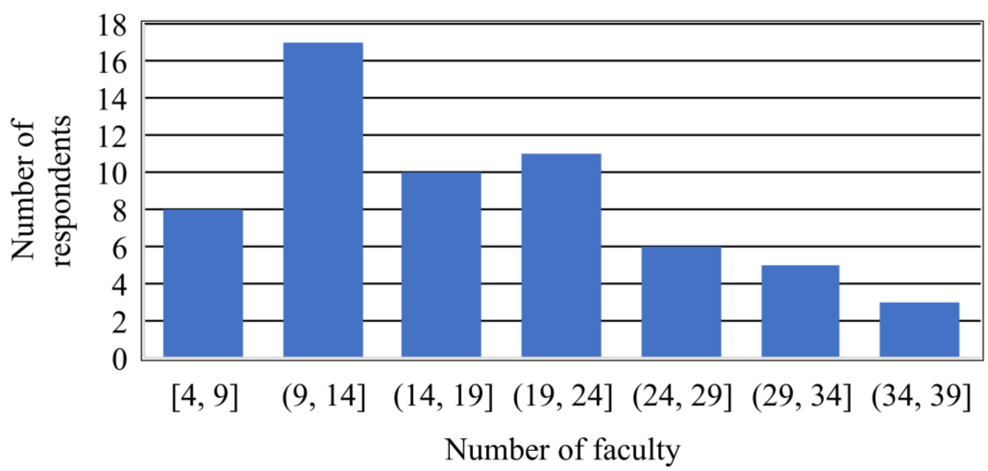


Figure 1.  Faculty size at responding institutions.

The distribution of design instructional staff size is given in Figure 2.  At half of the institutions, design is taught or mentored by only one faculty member.  The median size is 1.5 faculty, and the average is 2.8.  The staff includes faculty (not graduate TAs) who teach, co-teach or mentor teams.  Over half of the responding instructors have at least three years of industrial experience, but 15% have no industrial experience, as shown in Figure 3.  A decade ago, about the same percentage (75%) of the design faculty reported significant industrial experience with an average of 11.6 years [1].  Design faculty are slightly more likely to be teaching-track (48%) than tenure-track (43%).  This is a substantial shift from 10 years ago, when 75% of the design faculty were tenure-track and 17% were teaching-track.  The design faculty are frequently not licensed professional engineers, as shown in Figure 4.

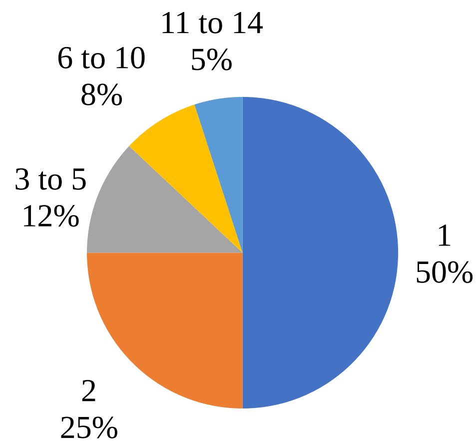


Figure 2.  Percent of institutions reporting different sizes of design faculty

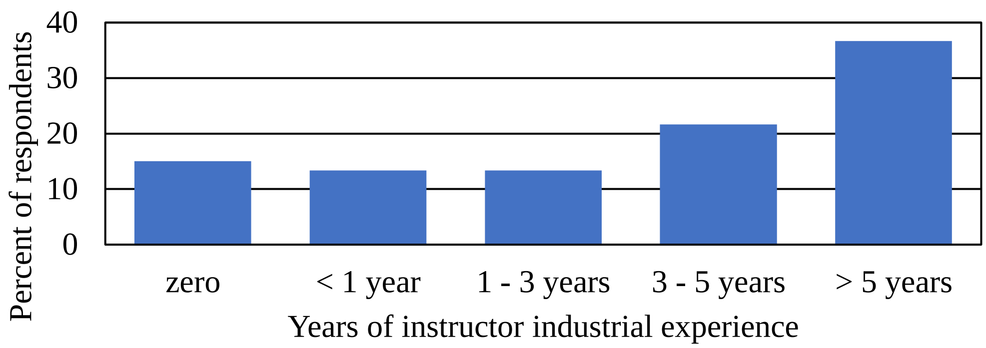


Figure 3.  Number of years of design instructor industrial experience

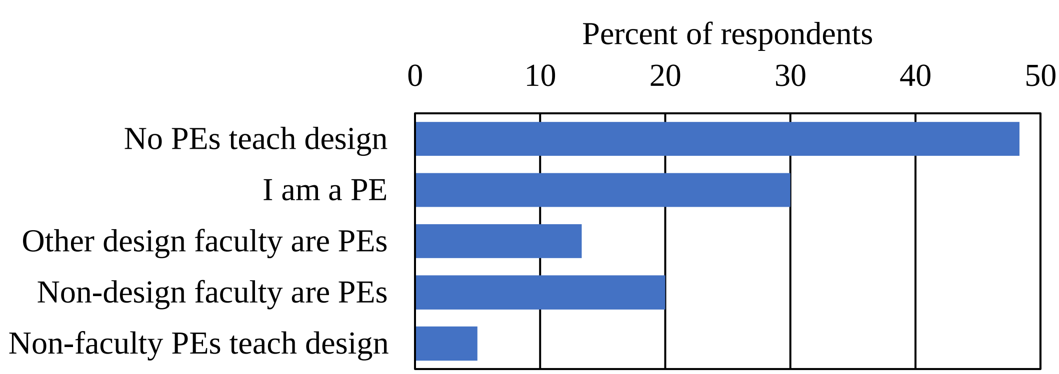


Figure 4.  Licensed professional engineer status of design and other faculty

Industrial collaborators are used in capstone design courses at 65% of the responding institutions. One example of industrial collaboration is the University of Colorado Boulder, with a newsletter article describing their course at [2].  At other institutions, industrial advisors read and comment on students' reports and meet them for project coaching.  At some institutions, industrial partners pitch projects which the students rank for their preferences in the team-formation process. Industrial partners frequently see the final presentations, but not all assess the final reports. A less time-intensive industrial collaboration is through safety and team-building exercises, instruction in start-ups and reading of P&IDs, and generally a real-world viewpoint.

The number of students enrolled in each section of capstone design showed large variation, in line with the institutions responding. The faculty teach courses with an average of 61 students per section. The standard deviation of students enrolled was 40, and the median was 49. The distribution of capstone students per section is given in Figure 5.

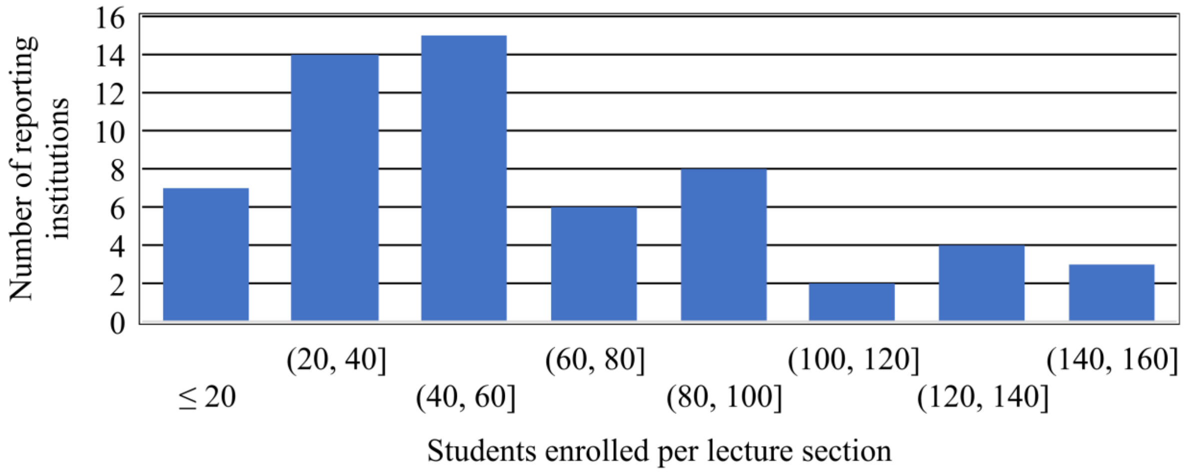


Figure 5. Student enrollment in each capstone design section at responding institutions

The number of students in each section tells only part of the story, as some institutions offer six sections of design courses over the academic year. In addition, half of the schools have more than one design faculty member. When enrollment in all sections of all capstone design courses is divided by the number of design faculty, the average is 79 students per faculty member, with a median of 45. The bimodal distribution is shown in Figure 6.

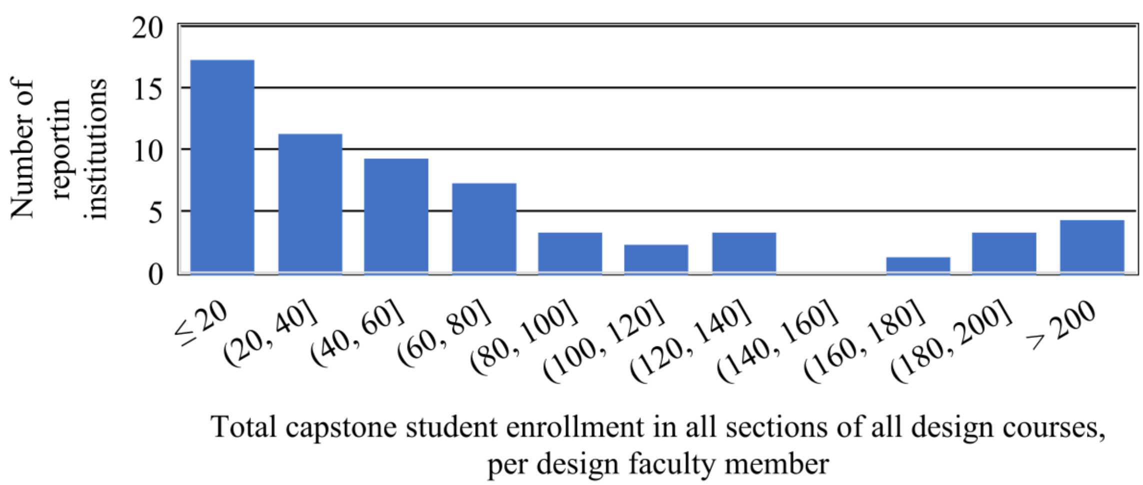


Figure 6. Total student enrollment in all capstone design sections, all capstone design courses, per design faculty member, at responding institutions

How do the design faculty spend their time with their students?  Regularly-scheduled contact hours in the capstone design course are nearly evenly split between content delivery (46%) and independent student work (49%).  The wide range of variability is indicated by the standard deviation of 22% for both categories.  The "other" category accounted for 6% of regularly-scheduled contact hours and included group meetings with instructor or mentor, student presentations, class discussion and tutorials, and exams.

Outside of those regularly-scheduled contact hours, the capstone design experience instructor spends nearly half of the workweek on other aspects of the design course, as shown in Figure 7.  Meeting with & mentoring teams, grading, course administration, preparing workshops or lectures, and open office hours together consume two instructor days per week, on average over the responding institutions.

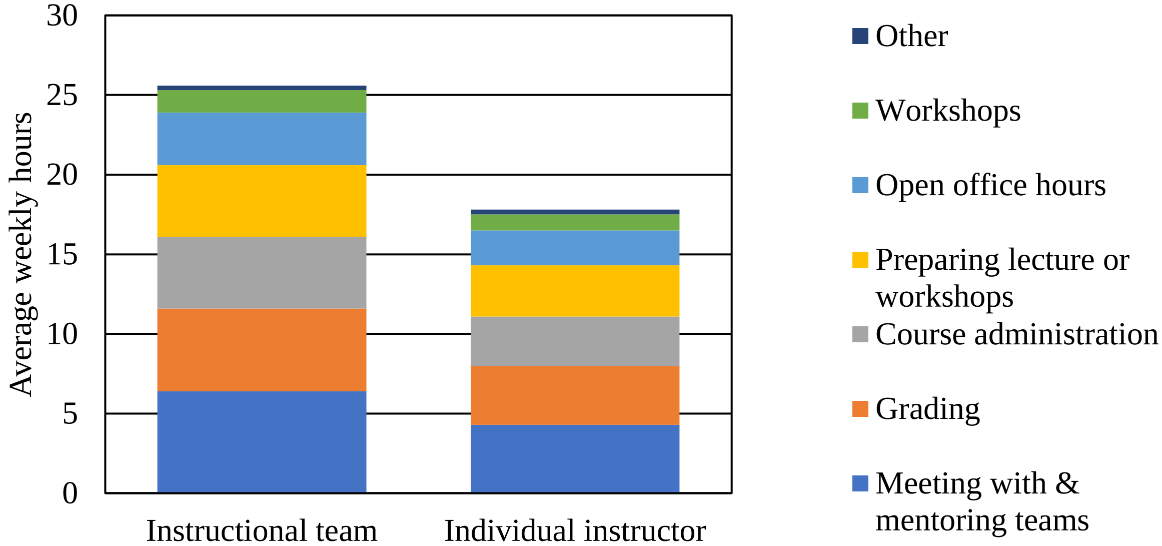


Figure 7.  Average hours per week for how a capstone design instructor or instructional team spends time on the experience

Faculty commonly use videos [3] and AIChE resources to prepare for design courses.  In Figure 8, the AIChE resources include SAChE modules [4], safety workshops [5], and design competition.  Magazines include Chemical & Engineering News (C&EN) [6], and Chemical Engineering Progress (CEP) [7].  Textbooks will be discussed in a later question.  Handbooks include Perry's Chemical Engineers' Handbook [8], and software includes Julia and process simulators (in a later graph).  Online resources are literature searches and SciFinder.

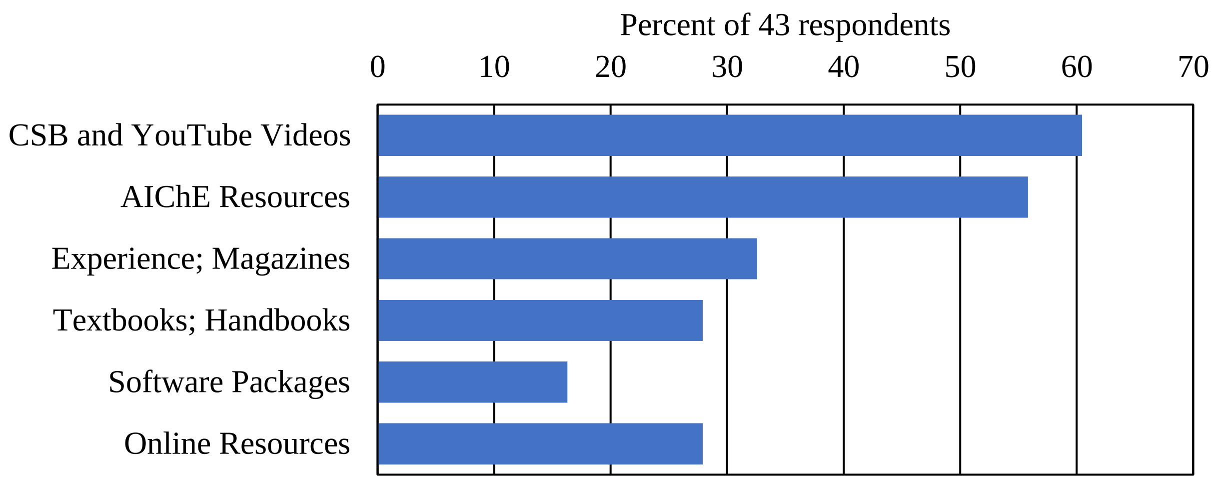


Figure 8. Resources used by faculty to prepare for capstone design courses

Team formation is an important aspect of the capstone design experience. Many faculty allow the students to either influence team formation or select their teammates, as shown in Figure 9. Other considerations in team formation were diversity, equity, & inclusion, academics, and schedule. Nearly a quarter of responding faculty form teams randomly. Many faculty used multiple factors when forming teams, but about 25% use only student-selected teams. Nearly half of the responding faculty adjust team sizes when teams cannot be equal sizes, with a 2:1 preference for smaller teams over larger teams.

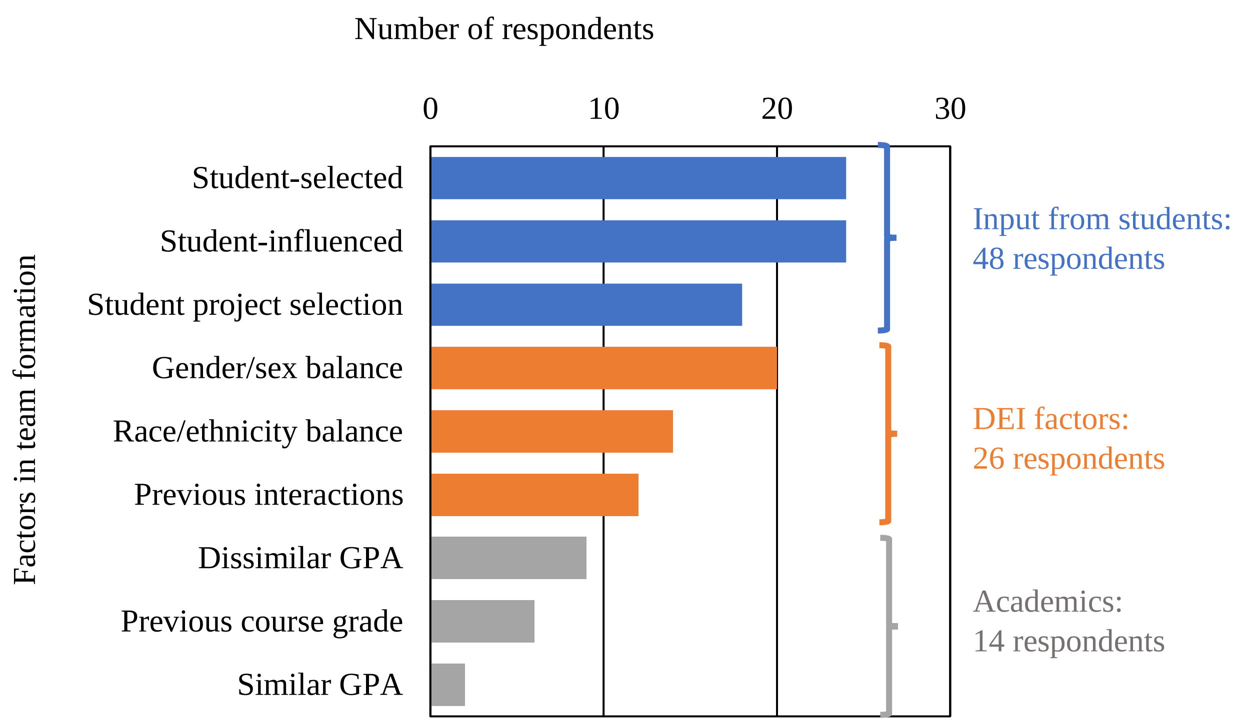


Figure 9. Number of responding faculty who use different factors in team formation for capstone design

Figure 9 generated considerable concern among the survey committee members. Are faculty assuming diversity, equity, and inclusion (DEI) categories, or are they asking students for them? Are we *allowed* to ask for them and use them? Are we *allowed* to know grades from previous courses and use them in team formation? Many team formation recommendations in the past [9], [10] have been to not isolate students from under-represented groups, but how are we to implement these recommendations given our concerns?

The survey committee chair contacted General Counsel at the University of Tulsa (her institution) for a clarification of these concerns in light of the Family Educational Rights and Privacy Act (FERPA) [11]. Please follow policies at your own institution in case they may differ. From General Counsel at this institution, schools are allowed to disclose academic records, including grades, to school officials with legitimate educational interest, such as faculty forming teams for a course. If a faculty member uses grades to form teams, the faculty member must not reveal how the groups are made. Students may deduce how the teams are made, but the faculty member is FERPA-compliant as long as the team-formation-scheme is not revealed by the faculty member. Categories that faculty might want to use for under-represented group status may or may not be part of the educational record, depending on how the information is gained, so that information may not be a FERPA issue. Faculty may ask for and use group status to form groups, but again faculty should not reveal their team-formation-schemes.

One team-making tool, CATME [12], has recently added a "Consent" button. This button allows the instructor to customize the visibility of student answers to three different options: share with the faculty, hide from the faculty, or student choice to share or hide. Students are told as they enter information whether faculty will be able to see it. In all cases, the student answers are still visible to the CATME algorithm so they can be used to form teams without isolated under-represented groups, for example. This is one solution to form teams using group status without asking the students to reveal group status to faculty.

The team size is an average of 4.0 with a standard deviation of 0.9 over the 60 responses. The range of team size is 1 to 8.

The survey committee grouped the particular challenges of teaching capstone design into five themes.

- Teaching students how to solve open-ended problems is a completely different way of thinking from earlier coursework. Students find it challenging to make decisions without all of the information.
- Project ideation and scoping: faculty must balance the amount of student agency over the project with instructor knowledge and information available to solve the problem.
- The course is labor-intensive (see Figure 7).
- The faculty must have the expertise (or be able to find it) to be useful to the students.

- The course has more student issues than many other courses:  student motivation, peer accountability, group formation, progress monitoring, and conflict resolution.

Now that the design experience has been covered from the point of view of the faculty, this paper will switch to design from the point of view of the student.

Design Experience

Design is included in the curriculum in many different ways.  Figure 10 shows how design is experienced at the different responding institutions.  Over two-thirds of the institutions have a 2-or-3-course capstone design sequence.  Only 26% of the institutions have a single capstone design course.  This is quite a shift from the 2012 survey, in which 28% of respondents had two courses and 47% had one capstone design course.  The survey in 1965 assumed that there were two design courses.

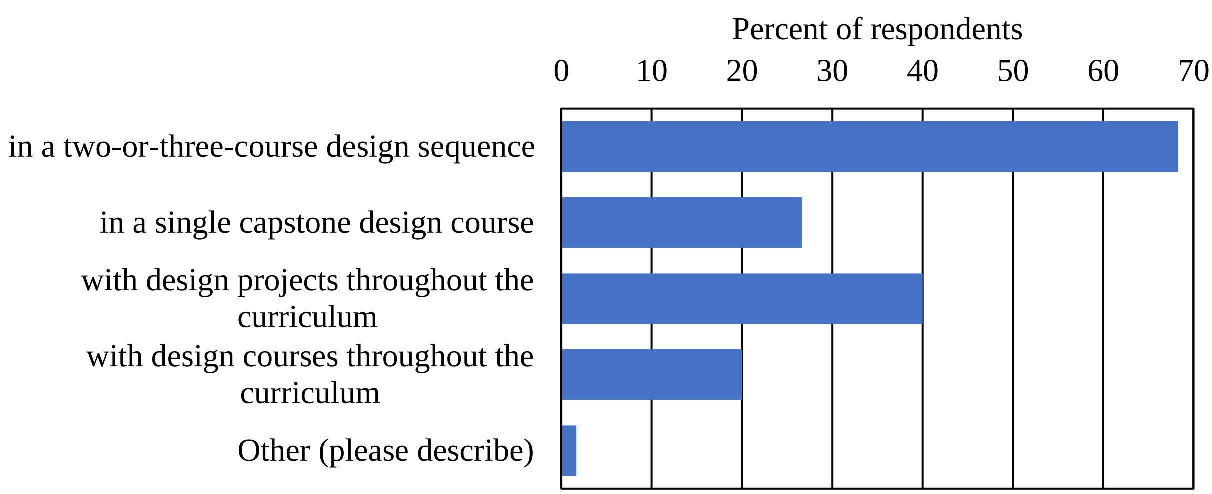


Figure 10.  How students experience design at responding institutions

Capstone design is not the only course with design content, as twenty percent of the institutions have design courses throughout the curriculum (a sophomore design course, a junior design course, and capstone design, for example).  Forty percent of the institutions have design projects in courses throughout the curriculum (a design project in fluids, one in heat transfer, one in reactor design, etc.).  The 2-or-3-course series has an average of 6.1 credit hours compared to the 4.7 credit hours for a single capstone design course.  The capstone design experience is 4.8 hours on average if there are design courses throughout the curriculum but 5.7 hours if there are only design projects sprinkled through the curriculum.  The survey question did not distinguish between semester and quarter credit hours, but 93% of the responding institutions are on the semester system.

Either the capstone design series or single course may be offered once per year or multiple terms. At 78% of the institutions, the capstone design course or courses are offered only once per year.

Design is offered twice per year at 20% of the institutions and three times per year at 2%. Offering design once per year is more common at institutions with a two-or-three course capstone sequence than at institutions with a single capstone course:  90% versus 50%.  There is a slight preference for offering a capstone design course in the spring semester or winter quarter (85% of respondents) over the fall semester or quarter (72%).  Capstone design is offered in the spring quarter at 7% of institutions, and 7% indicated “other”.

Design Projects

This section of the paper describes the capstone design projects and computer resources: how many design projects each student completes, how many design projects each cohort completes, the project topics, and types of projects.

Students have many options for computers to work their design projects.  Faculty could select more than one option for this question.  Students using their own computers was the most popular selection (87%). Just over half of the institutions (53%) provide virtual labs for the students to access university software.  College computer labs (60%) are more common than both departmental (38%) and institutional (42%) computer labs.

Students at two-thirds of the institutions work one culminating design project in the capstone design experience.  Data are given in Figure 11.  The students within the same course may all be working on the same project, or they may be doing different projects.  The number of unique projects worked by the entire student enrollment is given in Figure 12.  The mode for the number of projects completed by the entire cohort is one, meaning that all of the students work the same design project.  Although this is the mode, it represents just over a quarter of the responding institutions.  The mean number of projects completed by a cohort is 8.6.

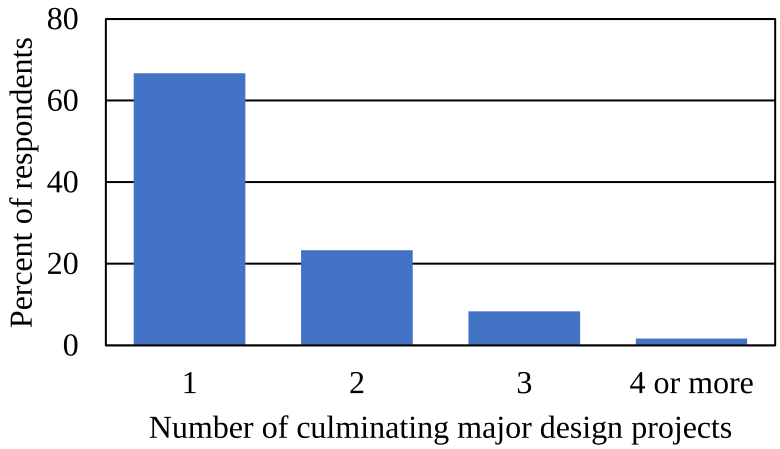


Figure 11.  Number of culminating major design projects in the capstone design experience

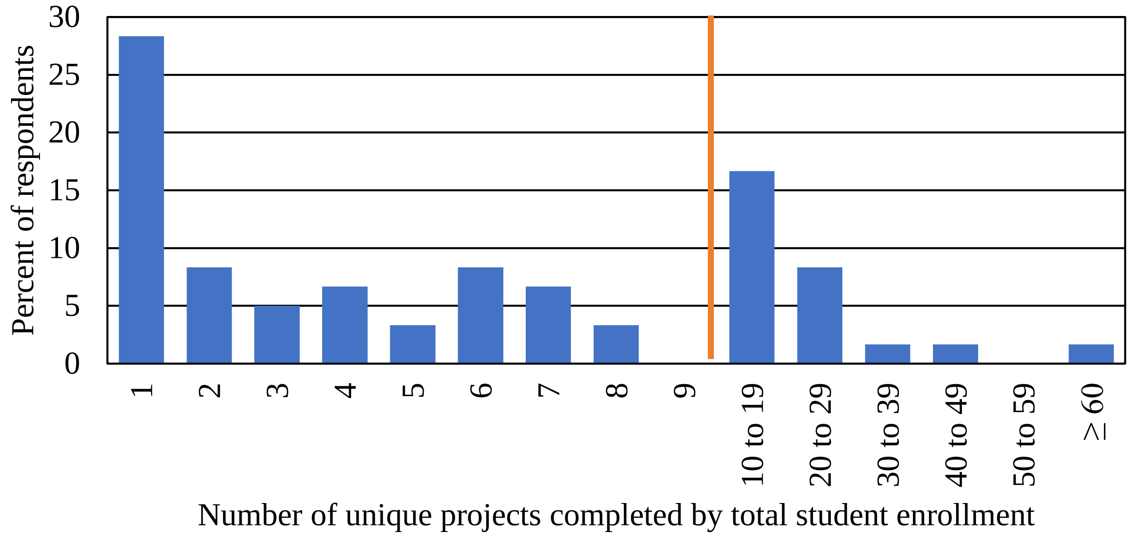


Figure 12. Number of unique projects done by the total student enrollment in the capstone design experience. “1” means that all of the students work the same design problem. Note the change of scale indicated by the orange line between 9 and 10.

The most common topic for capstone design projects is by far commodity chemicals, as shown in Figure 13. Commodity chemicals projects were completed by three times more student teams than any other topic and by about as many teams as the next three topics – polymers, bioengineering/tech/processing, and specialty chemicals – combined.

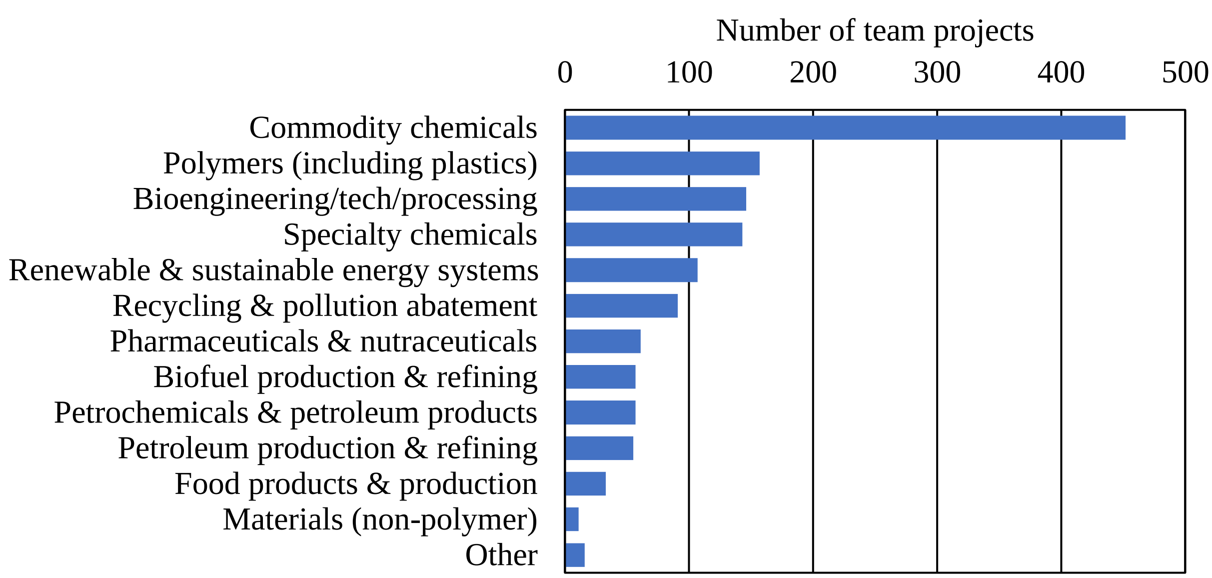


Figure 13. Number of student teams completing a design project in the topics shown

The AIChE Design Competition problems are not used at most responding institutions (Figure 14). Only 15% of responding institutions work the current problem under competition conditions.

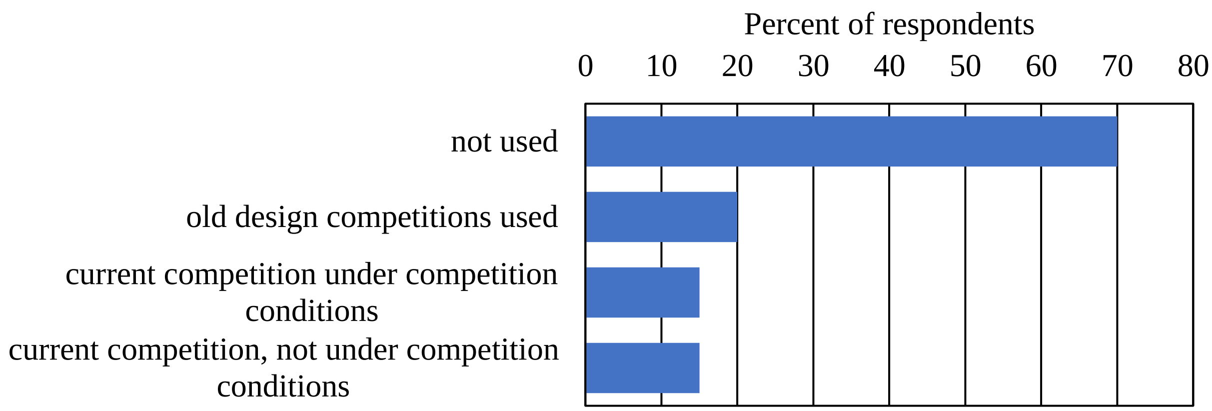


Figure 14. How responding institutions use the AIChE Design Competition in the capstone design course

Two-thirds of the design projects themselves are a theoretical design as opposed to one that is based on experiments done by the students or one in which the students build a prototype (Figure 15). The large "other" category included two different types of schools. At some institutions, the project type depends on the semester or is different for different projects within the same course. At others, the project is a combination of two categories, such as a theoretical design based on experiments run by the students.

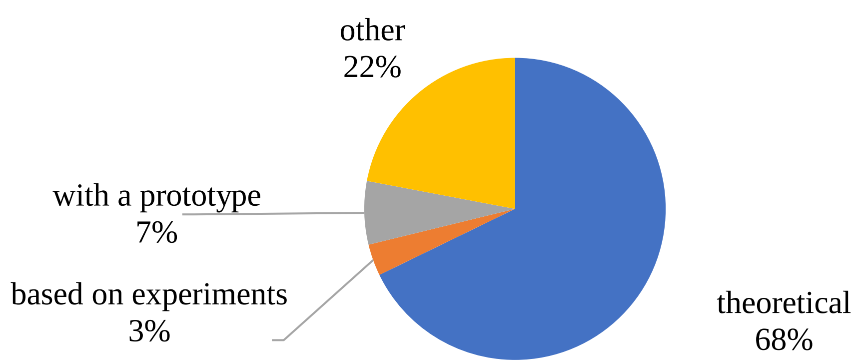


Figure 15. Percent of responding institutions with different types of capstone design projects

Other Course Details

At most responding institutions, students meet with someone for formal feedback every one or two weeks, as shown in Figure 16. These feedback meetings could be with faculty, industry or graduate student mentors.

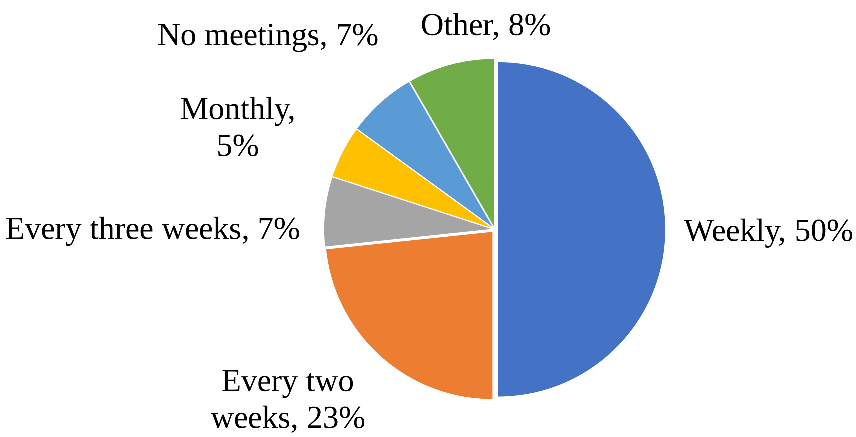


Figure 16. Percent of responding institutions with different frequencies of formal feedback meetings on design progress

Capstone design is time-intensive for the students as well as the faculty. Students at most institutions spend 6 – 10 hours per week on their design projects. Figure 17 reports the distribution of work hours by institutions. Faculty were asked to use students' self-reported information from an institutional survey if possible.

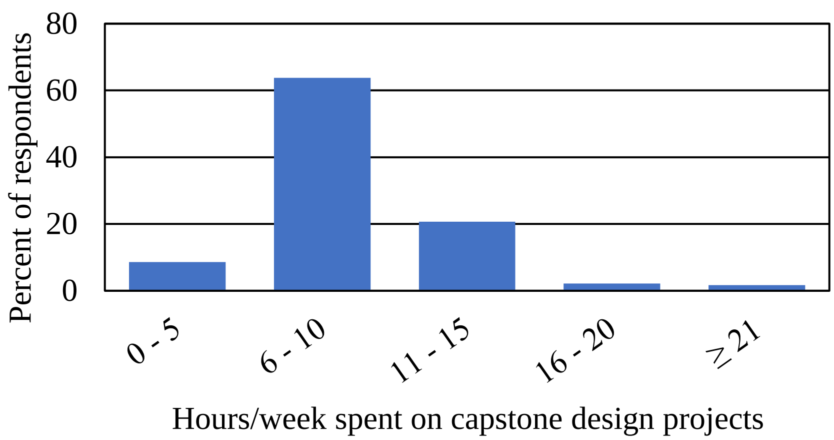


Figure 17. Average number of hours per week spent on capstone design projects by students

The most common assessments are team projects, oral presentations, simulations, process flow diagrams (PFDs), and teamwork evaluations (Figure 18). Oral presentations are used in about twice as many institutions are poster presentations. PFDs are required at about three times more institutions than piping & instrumentation diagrams (P&ID). Finals are given at about half as many institutions which use exams. The average of the 20 respondents who give exams is 2.1 exams per semester. Homework is almost evenly split between individual and team.

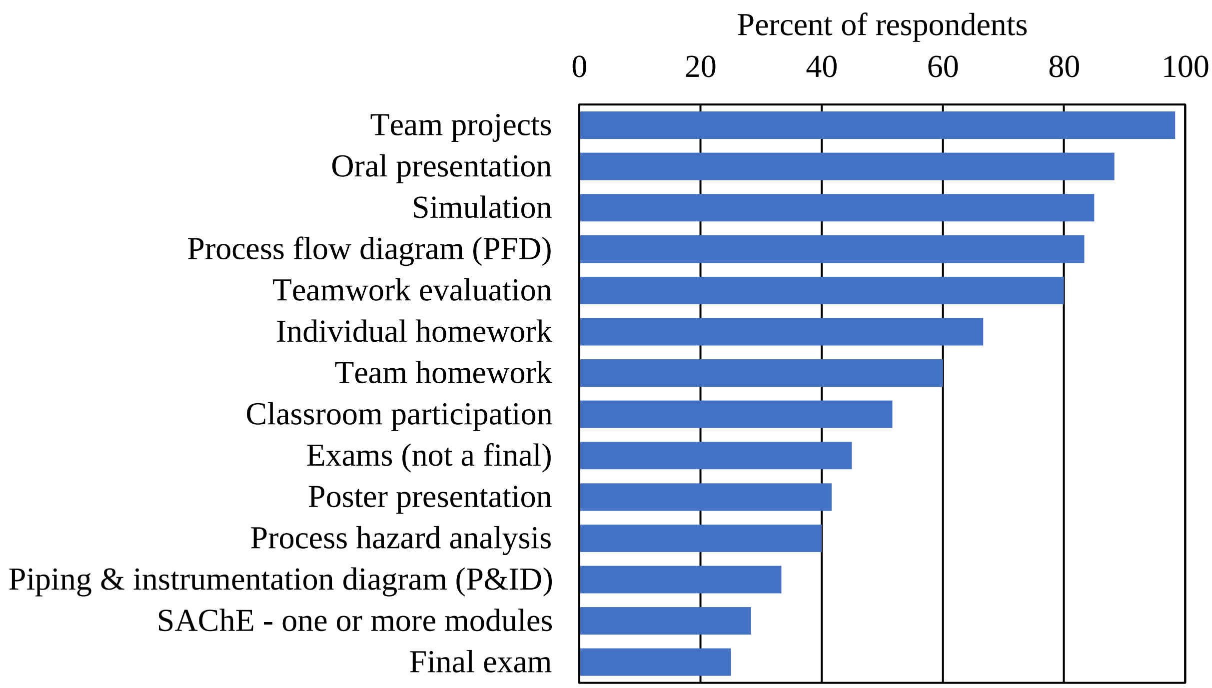


Figure 18. Assessments used in capstone design experiences

Lectures and software/programming instruction are the most common instructional activities for capstone design experiences, as seen in Figure 19. Guest speakers are used in many more institutions than other courses earlier in the curriculum [13], [14].

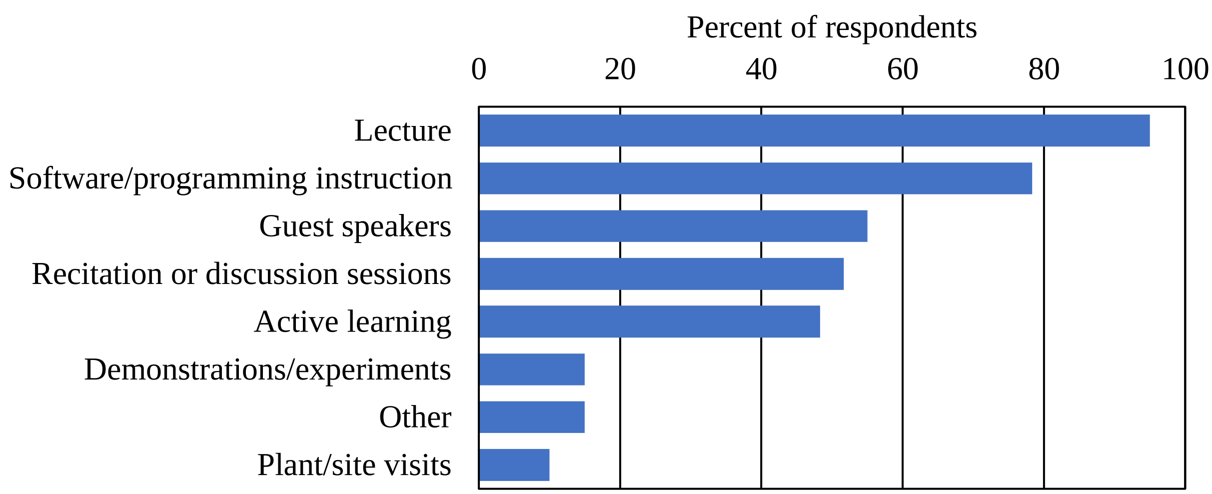


Figure 19. Percent of respondents which include various instructional activities in the capstone design experience

Multidisciplinary aspects were described by sixteen respondents, and these are given in Table 1. Faculty who do not include multidisciplinary aspects may do so because they are not sure how to include it or it is included elsewhere in the curriculum.

Table 1. Ways in which multidisciplinary aspects are included in the capstone design experience

| Responses | Description |
|---|---|
| 6 | some or all projects done with students from other departments/programs (MechE, entrepreneurship design sequence, etc.) |
| 5 | lectures/course content from another field |
| 3 | project advisors/support from another department/field |
| 1 | collaborate with another course |
| 1 | teams composed of students from different tracks/specialties within ChE |

As mentioned in Figures 18 and 19, software is an important part of the capstone design experience. Figure 20 presents the percentages of respondents who use different software packages. Aspen Plus, spreadsheets, and MATLAB are the most commonly used software for these respondents. The dominance of these software packages is unchanged from 2012, but ChemCAD was more frequently used in 2012 [1].

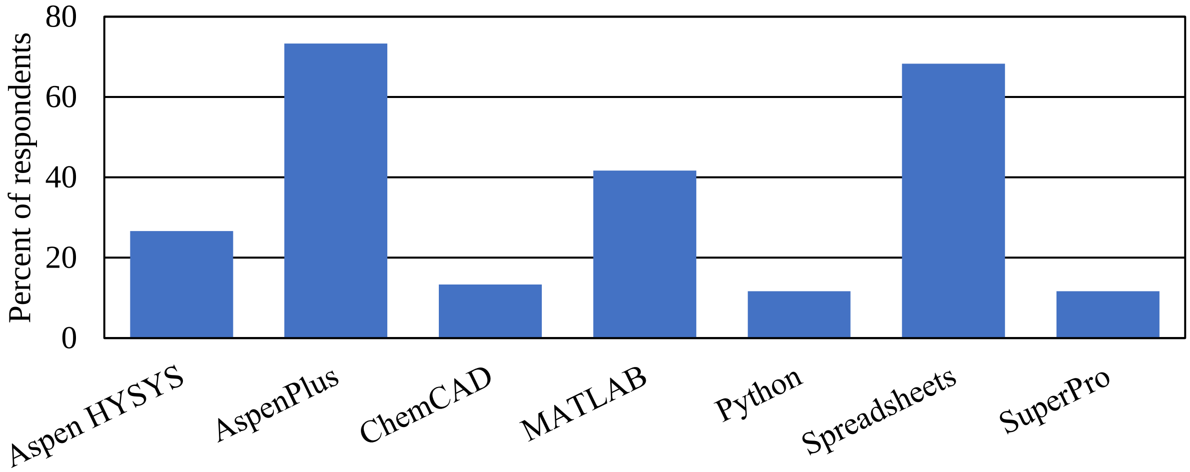


Figure 20. Percent of responding institutions using different software in the capstone design experience

The most frequently used textbook is by Turton, Shaeiwitz, Bhattacharyya, and Whiting [15], as seen in Figure 21 [15], [16], [17], [18], [19]. This textbook was also the most popular in 2012 [1]. Most (72%) responding faculty felt there was no need for textbook improvements, but a few faculty felt the textbooks were too big or needed primary references or updates. Topics suggested for textbook improvements (and the # of times each was suggested) were sustainability (8), design process steps (8), product design (4), process simulation (4), and teamwork (2).

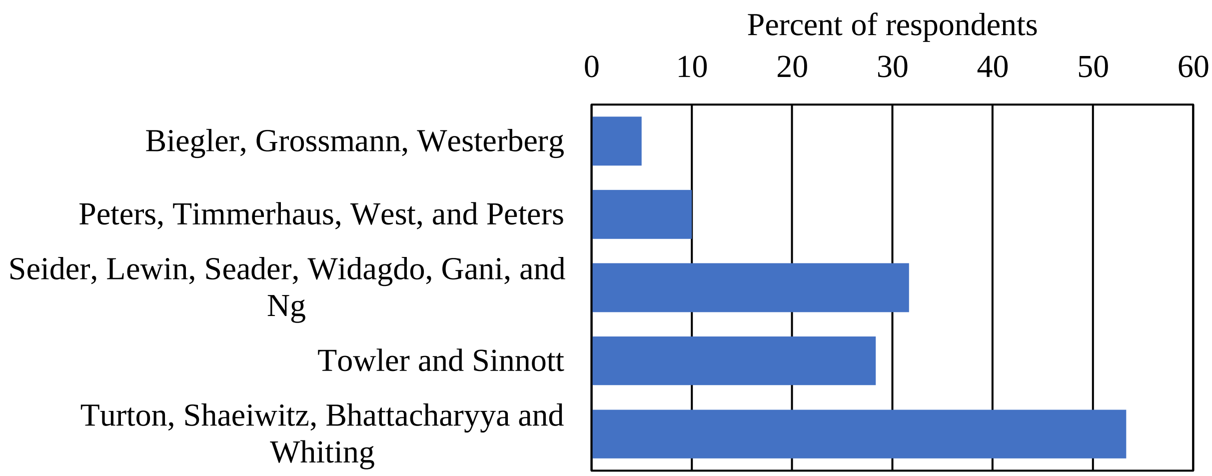


Figure 21. Percent of responding institutions using various textbooks for the capstone design experience

The surveyors were interested in the coverage of potential technical topics in the capstone design experience. Definitions of categories were given with the question, as found in Appendix A. As seen in Figure 22, all topics with the word "Process" were covered in-depth at over 50% of the responding institutions. Plant design was also covered in-depth at over 50% of the institutions. Other technical topics were more lightly covered. Results were similar in 2012 [1], with product design being taught at fewer institutions than process design/simulation/economics and plant design.

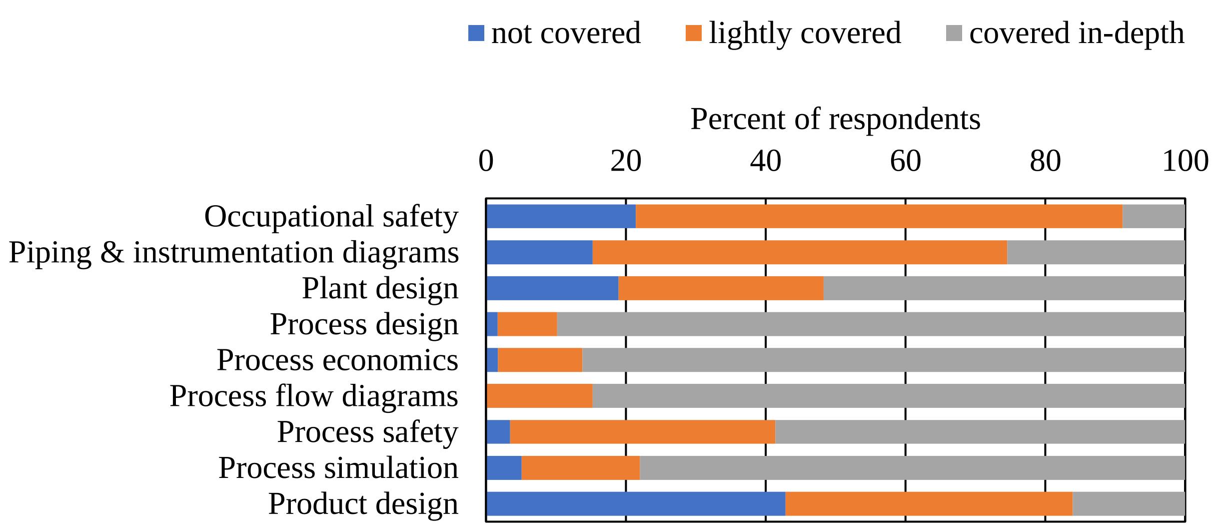


Figure 22. Coverage of technical topics in the capstone design experience

A similar question asked about the coverage of professional skills in the capstone design experience (Figure 23). Only professional communication and teamwork skills are covered in-depth at 40% or more of responding institutions. Teamwork and ethics were both taught at a majority of institutions in 2012 [1], but most of these topics were not on the survey then. All of the topics listed are covered at least lightly in a majority of responding institutions except negotiating skills, which was also low on the topics taught list in 2012.

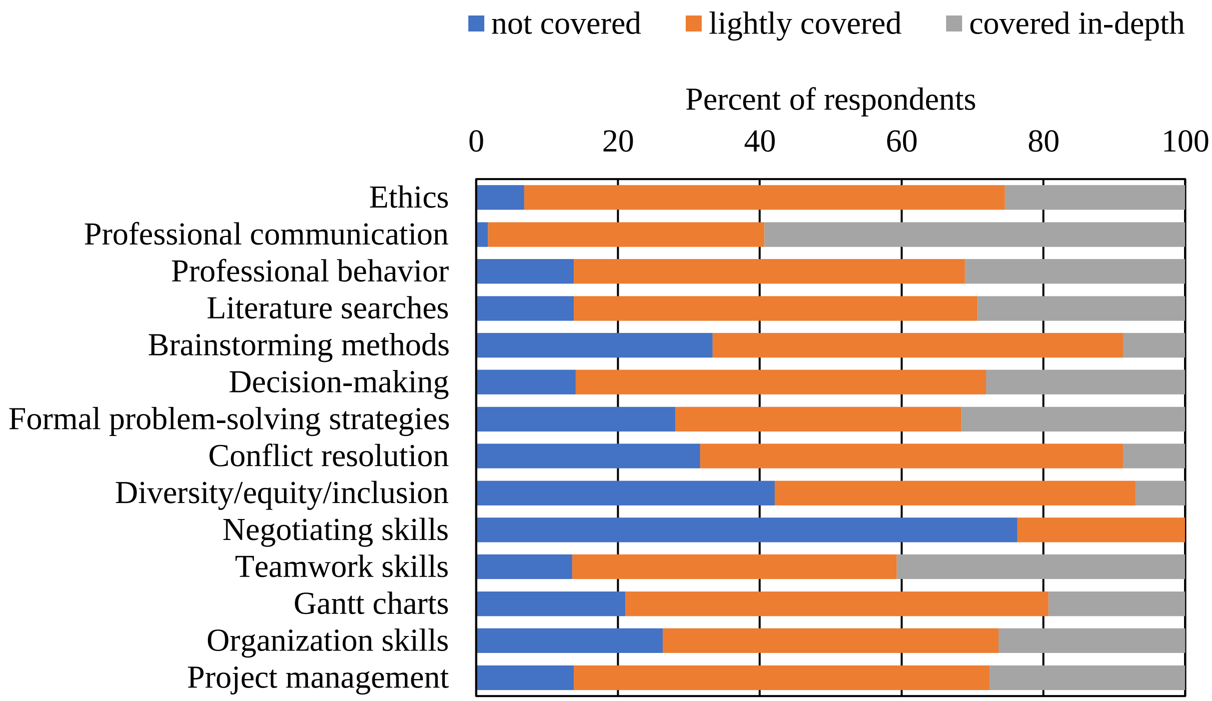


Figure 23. Coverage of professional skills topics in the capstone design experience

Sustainability topics were the subject of a similar question. Figure 24 shows that no listed sustainability topic was covered in-depth at a majority of responding institutions. All of the listed topics were covered at least lightly at a majority of institutions. The survey question had many topics that were not covered at more than 50% of responding institutions, and these do not appear in Figure 24. The "not-covered" topics were environmental justice, circular economy, resilience, environmental cost accounting, life cycle assessment, and supply chain management. In 2012, energy integration, waste minimization, sustainability/life cycle analysis, and lost work analysis were the topics taught in the sustainability area [1].

A survey question about distinctive features not already described yielded responses in two different groupings: student-generated projects (7 responses) and industry-sponsored projects (5 responses).

> "Essentially all the projects are suggested by the students (though many take substantial refinement to make into good projects)"
>
> "Our students select a product or a raw material for which they will propose a process with strong societal component."
>
> "We have industrially sponsored projects some years which the students quite enjoy. People from industry judge the oral presentations and give prizes."
>
> "We scope the project in a way that it is helping the local company and at the same time challenging the students in all the required engineering skills."

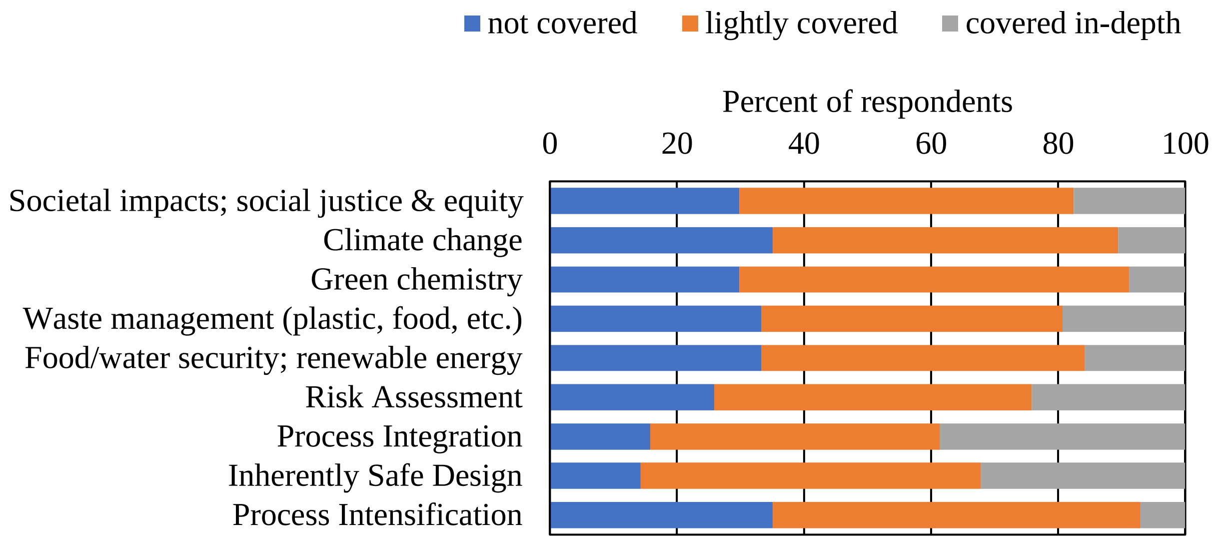


Figure 24. Coverage of sustainability topics in the capstone design experience

ABET-related Topics

Capstone design is a fundamental part of ABET accreditation, given that Criterion 5d requires a culminating major engineering design experience [20]. In addition, it is one of the last courses in the curriculum, so over 60% of responding institutions use the capstone design experience to assess all ABET outcomes except Outcome 6 related to experimentation. Table 2 presents the numbers.

Table 2. Percent of responding institutions which use the capstone design experience to assess different ABET outcomes

| Outcome | Percent of Respondents | Outcome | Percent of Respondents |
|---|---|---|---|
| 1 | 63 | 5 | 77 |
| 2 | 92 | 6 | 28 |
| 3 | 88 | 7 | 72 |
| 4 | 82 | | |

ABET's Criterion 5.d. [20] requires the incorporation of appropriate engineering standards in the culminating major design experience. Some of the ways that faculty incorporate engineering standards are given below.

- Industrial practitioner provides guidance as instructor or mentor regarding standards.
- Students required to review standards and regulations pertaining to chemicals, materials, structure, safety, and environments to be applied as appropriate.
- Standards are required as an explicit section in design report (Storage tanks most common need).
- Report has students identify relevant standards, regulations, and codes that would apply to further development.
- Students specify discharge standards for all chemicals in process.

The responses to a question about how engineering standards are applied revealed that design faculty are confused about what is considered an engineering standard.  Table 3 lists what may and may not be used for engineering standards.  While the items list in the second column are good practices to follow, they do not rise to the level of an engineering standard.

Table 3.  Items that are and are not engineering standards

| Engineering Standards | Not Engineering Standards |
|---|---|
| Current good manufacturing principles (cGMP), if relevant | Using standard symbols on flow sheets and P&ID diagrams |
| American Society of Mechanical Engineers (ASME) Code, American Petroleum Institute (API) Standards for storage vessels, piping, etc. | Using accepted design heuristics during conceptual design of process equipment |
| National Fire Protection Association (NFPA) codes for flammable storage and handling | Using GANTT charts or similar tools for project management |
| Occupational Health and Safety Administration (OSHA) Process Safety Management (PSM) requirements for safety | Process heuristics |
| US Environmental Protection Agency (EPA) regulations for safety and environmental impact, including Risk Management Process (RMP) | Considering Recognized and Generally Accepted Good Engineering Practices (RAGAGEP) when synthesizing systems for basic process control, pressure relief, and emergency shutdown |
| International Building Code (IBC) for buildings | |

Societal impact is part of ABET Outcome 3, “an ability to apply engineering design … with consideration of …global, cultural, social, environmental, and economic factors” [20].  Societal impact is included in the report or presentation at over half of the responding institutions and is covered in class lectures and discussions at a lower rate.  Environment, health & safety, and sustainability are the most commonly incorporated societal impact topics, as seen in Figure 25.

Diversity, equity, and inclusion (DEI) will be added to ABET criteria in coming accreditation cycles [20].  The survey asked how DEI are incorporated into teamwork.  DEI training or topics are specifically included at 27% of the responding institutions.  They may come up at 31%, and DEI are not included at 42% of responding institutions.  DEI topics appeared in

- inclusion topics for professional development (4 responses),
- project topic related to societal impact (3),
- diverse guest speakers or industry partners (2), and
- ethics (2).

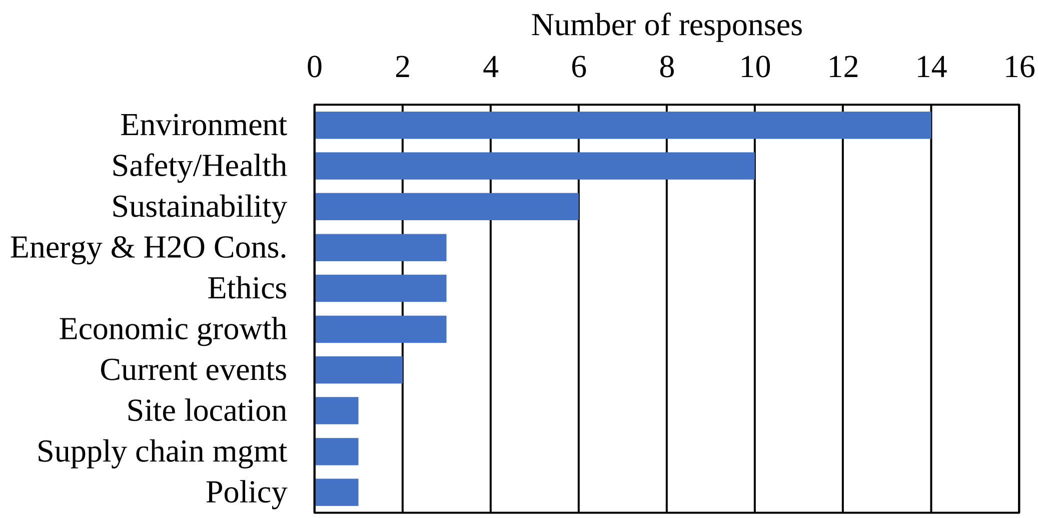


Figure 25. Societal impact topics included in the capstone design experience

A further breakdown of DEI training or topics is given in Figure 26. When DEI topics are not specifically included, they are usually addressed in team creation and teamwork evaluations. Inclusion topics for teamwork is the most common aspect covered when DEI topics are specifically included.

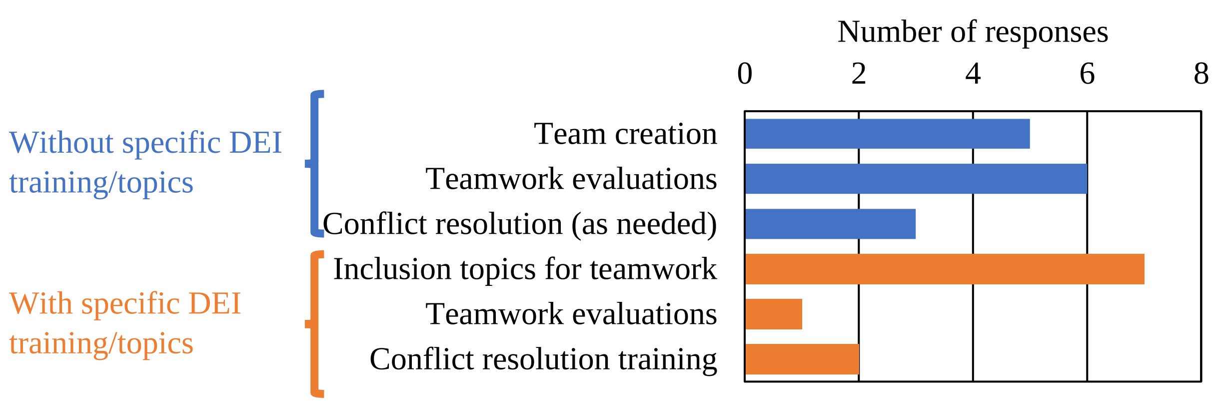


Figure 26. How DEI is incorporated into teamwork in the capstone design experience, broken down by whether or not DEI topics are specifically covered

Comparisons to Capstone Design in Other Disciplines

A proceedings paper from 2009 [21] reported on a survey of faculty, students, and industry from civil, chemical, electrical, general, and mechanical engineering about capstone design. Chemical engineering faculty were only 10 of the 48 responding faculty, so the chemical engineers in the survey did not sway the results too strongly. The faculty in this set had much more industrial experience than our chemical engineering faculty: 49% of the respondents had more than 5 years of industrial experience. The faculty were asked about the expected outcomes of a capstone design project, similar to our Figure 15. Faculty were able to make more than one selection. An analytical solution was expected by 70% of the faculty, which is very similar to the 68% in our survey for a theoretical design. A working, demonstrable solution was expected by 85% of their faculty, which is much higher than the 7% prototype in our survey, even if it is combined with some of the "other" category. Similarly, over 60% of their faculty expected a usable, implementable, or commercial solution, which does not appear explicitly in our survey. Their strong expectation for a prototype or commercial solution may arise from it being easier to produce a commercial solution or prototype for a mechanical or electrical engineering design project than for a chemical engineering design project. A prototype of a commodities chemical plant (the most common project in our survey; see Figure 13) is not a reasonable task for a 3-credit-hour course.

Nilsson, Hall, and Welch reported on a survey for civil engineering similar to ours [22], but this survey matches the timeframe of our previous survey a decade ago. Chemical engineering was similar to civil in 2012 in terms of 3 credit hours for one course, but we have shifted to two courses and closer to 6 credit hours. Chemical engineers spent less time per week on capstone design than the civil engineers (10 hr/week). Our projects were more likely to be theoretical projects than civil engineers'. The team size was about the same (4 students), but civil engineering teams were more likely to be multidisciplinary (49%) than chemical engineering design teams, as they have sub-disciplines to use.

Howe, Poulos, and Rosenbauer reported on the 2015 Capstone Design Survey of multiple engineering disciplines [23]. In this survey, 55% of respondents had a 2-course capstone sequence and 31% had a single course, which is slightly more towards a single course than our current survey. Over 60% of these teams are 4 students or smaller, which is similar to chemical engineering capstone design teams.

## Concluding Remarks

The capstone design experience is often highly appreciated by the students after they graduate:

> "Students are often frustrated in the course, however feedback from early alumni is typically that it is one of the courses that most prepare them to be successful on their job."
>
> "Our design program has been one of the highest ranked experiences by our undergraduate students in surveys and exit interviews."

Some changes have been noted since the 2012 survey over capstone design. Teaching-track faculty are much more likely to be teaching capstone design than before, 17% to 48%. The capstone design experience is much more likely to be a 2-course sequence than was reported in 2012, from 28% to 68%. Other aspects of the course have remained the same, such as team formation being a major concern, the most popular textbook, and the most popular software packages.

Most commonly, students complete one culminating, theoretical design project over commodity chemicals. The design team was formed with at least some input from the student and a consideration of DEI factors by the faculty member, as allowed by FERPA if the faculty member's algorithm is not revealed. Technical topics and professional communication skills are covered in-depth in the course. There is one instructor for the course who has some industrial experience. The instructor is not a licensed professional engineer but does collaborate with industrial partners for the course. The instructor averages 17 hours per week outside of regularly-scheduled contact hours on the course activities.

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Appendix A: AIChE EdDiv Capstone Design Survey 2022

Q1 Thank you very much for responding to this survey. The AIChE Education Division Survey Committee asks departments yearly about the current state of undergraduate education in a particular area of chemical engineering. This year, we are focusing on capstone design within engineering programs that include "chemical", "biochemical", "biomolecular", or similar modifiers in their titles. We hope that this survey can be fully completed in 20 minutes or less by someone who teaches capstone design. Previous recent surveys have been on material & energy balances, the first-year experience, Unit Operations Laboratory, Thermodynamics, Design, Transport, Controls, Kinetics and Reactor Design, and the curriculum as a whole. Our collected publications archive is available through this Google drive link. Questions? Please contact Laura Ford (committee chair) at laura-ford@utulsa.edu. Thank you for your help!

Q2 Definition: a capstone design experience contains "a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work" (ABET 5.d). Process, product, and plant design are all included. This capstone design experience may be one or more courses.

Q3 First, we'll ask some questions about you, your department, and your program in general.

Q4 Name of your institution ________________________________________________________________

Q5 Name of the person completing the survey________________________________________________

Q6 How many years of industrial experience do you (a design instructor) have?

- zero
- < 1 year
- 1 - 3 years
- 3 - 5 years
- 5 years

Q7 Which track are you (a design instructor) on?

- Adjunct
- Teaching track
- Tenure track
- Visiting professor
- Other (please describe) ________________________________________________

Q8 Does your institution use quarters, trimesters, semesters, or another system?

- ○ Quarters
- ○ Trimesters
- ○ Semesters
- ○ Other (please describe) ________________________________________________

Q9 Number of faculty and instructors who teach in your department.
(Please include professors of practice, visitors, adjuncts, instructors, and tenured/tenure track; please do not include graduate teaching assistants or research faculty.)_________________

Q10 Which accreditation agency, if any, reviews your program?

- ☐ ABET
- ☐ Engineers Canada/Canadian Engineering Accreditation Board/CEAB
- ☐ Other (please describe) ___________________________________________

Q11 What is the computing environment for your students? Please choose all that apply.

- ☐ Computer labs maintained by the Department
- ☐ Computer labs maintained by the College
- ☐ Computer labs maintained by the Institution
- ☐ Students use their own computers
- ☐ Virtual lab through AppStream or other virtual desktops

Q12 Students in your program experience design

- ☐ with design courses throughout the curriculum
- ☐ with design projects throughout the curriculum
- ☐ in a two-or-three-course design sequence
- ☐ in a single capstone design course
- ☐ Other (please describe) _________________________________________

Q13 The first series of questions will cover the capstone design experience - the course or courses in the culminating design experience. Please answer for course(s) taught in the 2021/2022 academic year.

Q14 Course number(s) and title(s) for the capstone design experience. __________________

Q15 How many times is each course in the previous question offered?

- ○ once per year
- ○ twice per year
- ○ three times per year
- ○ other (please describe) __________________________________________________

Q16 In which term(s) is your capstone design experience offered? Check all that apply.

- ☐ Fall semester/quarter
- ☐ Spring semester/Winter quarter
- ☐ Spring quarter
- ☐ Other (please describe) ________________________________________

Q17 How many total credit hours is the capstone design experience? ______________________

Q18 How many sections of the capstone design experience were offered in the 2021/2022 academic year?___________________________________________________________________

Q19 What was the total enrollment in all sections of capstone design in 2021/2022?__________

Q20 How many "culminating major design" projects do students typically do within the capstone design experience?

- ○ 1
- ○ 2
- ○ 3
- ○ 4 or more

Q21 For the culminating major engineering design project, how many unique projects were completed by the total student enrollment? For example, if all students completed the same project, enter 1. _________

Q22 What is the target number of students in each capstone design team?________________

Q23 Which of the following are considerations used in forming the culminating design project team? Select all that apply.

- ☐ Student-selected
- ☐ Student-influenced (e.g., choose one person to work with/not work with)
- ☐ Student project selection/ranking
- ☐ Randomly
- ☐ Group dissimilar GPA
- ☐ Group similar GPA
- ☐ Student schedule
- ☐ Gender/sex team balance
- ☐ Race/ethnicity team balance
- ☐ Communication skills (e.g., English as a second language, written/oral skills)
- ☐ Teams that are +1 in size when numbers don't work out
- ☐ Teams that are -1 in size when numbers don't work out
- ☐ Academic performance in a prerequisite course(s)
- ☐ Previous interactions in a group/team project
- ☐ Other (please describe) ______________________________________________

Q24 Are there licensed professional engineers (PEs) on your faculty or capstone instructional team? Choose all that apply.

- ☐ No
- ☐ I am a PE
- ☐ Other faculty involved in teaching capstone design are PEs
- ☐ Other faculty who are not involved in teaching capstone design are PEs
- ☐ One or more non-faculty PEs are part of the design instructional team

Q25 Do you have industrial collaborators in the capstone design course?

- ○ No
- ○ Yes

Q26 Please describe the role of industrial collaborators in formulating or supervising course projects in the capstone design course. ________________________________________

Q27 How many total faculty (not graduate TAs) teach or co-teach the capstone design experience or mentor teams?_________________________________________________

Q28 Considering the regularly-scheduled contact hours in the capstone design experience, what percentage of time is devoted to the following?

| | 0 10 20 30 40 50 60 70 80 90 100 |
|---|---|
| Content delivery | |
| Independent student work time | |
| Other (please describe) | |

Q29 Which of the following activities are a component of your capstone design experience? Select all that apply.

- ☐ Lecture
- ☐ Recitation or discussion sessions
- ☐ Active learning (clickers, think/pair/share)
- ☐ Demonstrations/experiments
- ☐ Plant/site visits
- ☐ Guest speakers
- ☐ Instruction in software or programming (please specify) ____________________
- ☐ Other (please specify) ________________________________________________

Q30 Please describe the instructor's time spent on the capstone design experience outside of regularly-scheduled contact hours, in average hours per week.

| | 0 4 8 12 16 20 24 28 32 36 40 |
|---|---|
| Course administration | |
| Grading | |
| Meeting with and mentoring teams | |
| Open office hours | |
| Preparing lecture or workshops | |
| Workshops (simulation, teamwork, project management, etc.) | |
| Other (please describe) | |

Q31 How frequently do students meet with anyone (faculty, industry, or graduate student mentor) for formal feedback on their progress?

- ○ weekly
- ○ every two weeks
- ○ every three weeks
- ○ monthly
- ○ there are no formal feedback meetings with a mentor
- ○ other (please describe) ____________________________________________

Q32 Approximately how much time each week does each student work on design projects in the capstone design experience? Please use students' self-reported information from an institutional survey if available.

- ○ 0 - 5 hours per week
- ○ 6 - 10 hours per week
- ○ 11 - 15 hours per week
- ○ 16 - 20 hours per week
- ○ at least 21 hours per week

Q33 What assessments or deliverables are required as a component in your capstone experience? Choose all that apply.

- ☐ Individual homework
- ☐ Team homework
- ☐ Individual lab reports
- ☐ Team lab reports
- ☐ Individual projects
- ☐ Team projects
- ☐ Teamwork evaluation, assessment, or peer review
- ☐ Essays
- ☐ Reflections
- ☐ Pre-announced quizzes (shorter than exams)
- ☐ Pop quizzes
- ☐ Exams (hour or longer, not a final) - please enter how many ________________
- ☐ Final exam
- ☐ Poster presentation
- ☐ Oral presentation
- ☐ SAChE - one or more modules
- ☐ Classroom participation
- ☐ Process flow diagram (PFD)
- ☐ Simulation
- ☐ Piping & instrumentation diagram (P&ID)
- ☐ Process hazard analysis (please list the software used) ____________________
- ☐ Other (please describe) ____________________________________________

Q34 The culminating design project is

- ○ a theoretical design
- ○ a design based on laboratory experiments
- ○ a design with a prototype built
- ○ other (please describe) ______________________________________________________

Q35 How do you use AIChE Design Competition problems in the capstone design course? Choose all that apply.

- ☐ I do not use the AIChE Design Competition problems.
- ☐ Students work old design competition problems
- ☐ Students work the current design competition problem under competition conditions
- ☐ Students work the current design competition but not under competition conditions

Q36 How many student teams completed projects in each category below in last year's capstone design experience?

Bioengineering, biotechnology, & bioprocessing ________________

Biofuel production & refining ______________________________

Chemicals, commodity __________________________________

Chemicals, specialty ____________________________________

Food products & production ______________________________

Materials (non-polymer) _________________________________

Petrochemicals & petroleum products ______________________

Petroleum production & refining ___________________________

Pharmaceuticals & nutraceuticals __________________________

Polymers (including plastics) ______________________________

Recycling & pollution abatement ___________________________

Renewable & sustainable energy systems ____________________

Other _______________________________________________

Q37 Please describe the "other" topics of design projects from the previous question.

________________________________________________________________

Q38 Which of the following software packages do students typically use as part of capstone design? Choose all that apply.

- ☐ Aspen HYSYS
- ☐ AspenPlus
- ☐ AVEVA Pro/II
- ☐ AVEVA Process Simulation
- ☐ BR&E ProMax
- ☐ ChemCAD
- ☐ Chemical Reactivity Worksheet
- ☐ Comsol Multiphysics
- ☐ Maplesoft Maple
- ☐ MATLAB
- ☐ MathCAD
- ☐ Polymath Plus
- ☐ Python
- ☐ Spreadsheets (Excel or similar)
- ☐ Symmetry
- ☐ VBA
- ☐ Wolfram Alpha
- ☐ Wolfram Mathematica
- ☐ Other (please describe) ________________________________________
- ☐ No software packages are used

Q39 Which textbook(s) is(are) primarily used in capstone design? Choose all that apply.

- ☐ No textbook is used
- ☐ Cussler and Moggridge; Principles of Chemical Product Design
- ☐ Erwin; Industrial/Chemical Process Design
- ☐ Martin; Industrial Chemical Process Analysis and Design
- ☐ Peters, Timmerhaus, West, and Peters; Plant Design and Economics for Chemical Engineers
- ☐ Seider, Lewin, Seader, Widagdo, Gani, and Ng; Product and Process Design Principles
- ☐ Smith; Chemical Process Design and Integration
- ☐ Towler and Sinnott; Chemical Engineering Design
- ☐ Turton, Shaeiwitz, Bhattacharyya and Whiting; Analysis, Synthesis, and Design of Chemical Processes
- ☐ Ulrich and Vasudevan; Process Design and Economics
- ☐ Engineering Economics textbook (please specify) ____________________
- ☐ Other ________________________________________________

Q40 Which of the following technical topics are covered in instructional materials for the capstone design experience? Process design includes the sequence of operations, operating conditions, equipment design, general plant layout, line sizes, and principle instrumentation. Reference Plant design includes detailed plant layout, general service facilities, and plant location. Reference Occupation safety includes lock-out/tag-out, grounding, security, etc. Process safety includes chemical reactivity, pressure relief, relief device design, interlocks, hazard analysis, etc.

| | not covered | lightly covered | covered in-depth |
|---|---|---|---|
| Occupational safety | ○ | ○ | ○ |
| Piping & instrumentation diagrams | ○ | ○ | ○ |
| Plant design | ○ | ○ | ○ |
| Process design | ○ | ○ | ○ |
| Process economics | ○ | ○ | ○ |
| Process flow diagrams | ○ | ○ | ○ |
| Process safety | ○ | ○ | ○ |
| Process simulation | ○ | ○ | ○ |
| Product design | ○ | ○ | ○ |

Q41 Which of the following professional skills topics are covered in instructional materials for the capstone design experience?

| | not covered | lightly covered | covered in-depth |
|---|---|---|---|
| Ethics | ○ | ○ | ○ |
| Professional communication | ○ | ○ | ○ |
| Professional behavior | ○ | ○ | ○ |
| Literature searches | ○ | ○ | ○ |
| Brainstorming methods | ○ | ○ | ○ |
| Decision-making | ○ | ○ | ○ |
| Formal problem-solving strategies | ○ | ○ | ○ |
| Conflict resolution | ○ | ○ | ○ |
| Diversity/equity/inclusion | ○ | ○ | ○ |
| Negotiating skills | ○ | ○ | ○ |
| Teamwork skills | ○ | ○ | ○ |
| Gantt charts | ○ | ○ | ○ |
| Organization skills | ○ | ○ | ○ |
| Project management | ○ | ○ | ○ |

Q42 Which of the following collaboration tools are students required to use? Choose all that apply.

- ☐ Discord, Slack, or similar
- ☐ Google Drive/Dropbox/Box, etc.
- ☐ Learning management system such as Blackboard or Canvas
- ☐ Microsoft Teams
- ☐ Other ________________________________________________

Q43 Are the following sustainability topics covered in instructional materials for the capstone design experience?

| | not covered | lightly covered | covered in-depth |
|---|---|---|---|
| Societal impacts; social justice & equity | ○ | ○ | ○ |
| Environmental justice | ○ | ○ | ○ |
| Climate change | ○ | ○ | ○ |
| Green chemistry | ○ | ○ | ○ |
| Waste management (plastic, food, electronic) | ○ | ○ | ○ |
| Food/water security; renewable energy | ○ | ○ | ○ |
| Circular Economy | ○ | ○ | ○ |
| Risk Assessment | ○ | ○ | ○ |
| Resilience | ○ | ○ | ○ |
| Environmental Cost Accounting | ○ | ○ | ○ |
| Life Cycle Assessment | ○ | ○ | ○ |
| Process Integration | ○ | ○ | ○ |
| Inherently Safe Design | ○ | ○ | ○ |
| Process Intensification | ○ | ○ | ○ |
| Supply Chain Management | ○ | ○ | ○ |

Q44 How are engineering standards applied in this course, as required in Criterion 5.d. for the ABET-defined culminating major engineering design experience? ________________________

Q45 Please describe any multidisciplinary elements in your capstone design course.__________

Q46 For which ABET Student Outcomes do you use the capstone design experience to assess the extent of the outcome's achievement at time of graduation? Choose all that apply.

- ☐ Outcome 1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
- ☐ Outcome 2. An ability to apply engineering design to produce solutions that meet specified needs with consideration for public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
- ☐ Outcome 3. An ability to communicate effectively with a range of audiences.
- ☐ Outcome 4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
- ☐ Outcome 5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
- ☐ Outcome 6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
- ☐ Outcome 7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Q47 The capstone design experience contributes to demonstrating possession of which of the EngineersCanada Graduate Attributes?  Choose all that apply.

- ☐ A knowledge base for engineering
- ☐ Problem analysis
- ☐ Investigation
- ☐ Design
- ☐ Use of engineering tools
- ☐ Individual and teamwork
- ☐ Communication skills
- ☐ Professionalism
- ☐ Impact of engineering on society and the environment
- ☐ Ethics and equity
- ☐ Economics and project management
- ☐ Life-long learning

Q48 Next are six open-ended questions that many would argue are the most important part of the survey. In these questions, we ask you to share what you do that could help other instructors improve their teaching. You may not have an answer for each question, but please try to share the information that makes your particular rendition of the course effective, unique, and valuable.

Q49 Is there a need for a better textbook for capstone design? In what topic areas can the text you now use be improved?________________________________________________

Q50 What are the particular challenges in teaching capstone design?____________________

Q51 What resources do you use to prepare for the course, including online resources such as SACHE modules, CSB videos, and UMich Equipment Encyclopedia? References may be helpful to faculty teaching the course for the first time. ______________________________

Q52 Please describe how you incorporate societal impact into the capstone design experience. _

Q53 Please describe how you incorporate diversity, equity, and inclusion into teamwork in the capstone design experience. ______________________________________________________

Q54 Please describe anything distinctive about your capstone design experience that has not been covered in the previous questions._____________________________________________

Q55 Any other comments on the capstone design experience of your students are welcome here.

Q56 Any comments regarding this survey are welcome here. _________________

Q57 We thank you for your participation! This helps all of us better understand the state-of-the-art in chemical engineering education. Please join us at Session 547 at the AIChE Annual Meeting, Wednesday 3:30 pm, to hear the results and discuss capstone design.

Q58 We will be compiling the results of this survey for distribution at the AIChE Annual Meeting and the ASEE Annual Conference. Would you like a copy of the processed results?

- ○ Yes
- ○ No

Q59 Please enter your email address so we may send you results. Your email address will not be used for any other reason. ______________________________________________________

Appendix B: Responding Institutions

Auburn University
Bucknell University
California Baptist University
California Institute of Technology
Carnegie Mellon University
Colorado School of Mines
Colorado State University
Columbia University
Cornell University
FAMU-FSU College of Engineering
Florida Tech
Lafayette College
Lamar University
Lehigh University
Louisiana State University
Louisiana Tech University
Manhattan College (2)
Montana State University
NJIT
New York University
North Carolina State University
Northeastern
Northwestern University
Ohio University
Penn State University
Rice University
Rowan University
SUNY Buffalo
SUNY College of Env. Sci. & Forestry
Syracuse University
Texas Tech University
The Cooper Union
The Ohio State University
The University of Texas at Austin
UConn
UMBC
University of Alabama in Tuscaloosa
University of Colorado Boulder
University of Dayton
University of Delaware
University of Houston
University of Idaho
University of Idaho
University of Illinois
University of Kansas
University of Kentucky
University of Minnesota, Duluth (2)
University of Missouri
University of North Dakota
University of South Carolina
University of Tennessee, Knoxville
University of Tulsa
University of Virginia
University of Wisconsin-Madison
Vanderbilt University
Washington University in St. Louis
WPI
Youngstown State University