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The 2015 Capstone Design Survey Results: Current Practices and Changes over Time*

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Capstone design courses are common in engineering design programs, but they vary substantially across institution and department. The goal of the decennial capstone design survey initiative is to capture data from capstone design courses every ten years to identify current practices and changes over time. In keeping with its predecessor surveys, the 2015 capstone design survey included questions on course logistics, pedagogy, evaluation, faculty, students, projects and teams, expenses and funding, and sponsors. The 2015 survey captured data from 522 respondents at 256 institutions, documenting the variety of implementation strategies for capstone design programs across the U.S. These data include quantitative and categorical responses about current practices and open-ended responses about respondent experiences and opinion. This paper presents the current state of capstone design education, draws comparisons across disciplines, and highlights changes within capstone design practices over the past 20 years. These surveys and the data gathered therein are an important first step in understanding, assessing, and ultimately improving engineering capstone design education.

Keywords: capstone design courses; capstone projects; capstone pedagogy; decennial survey

1. Introduction

Capstone design courses provide a major design experience for engineering students, usually during their final year of undergraduate study. Although these courses are common across engineering programs in the U.S., they vary substantially in the way they are implemented. The first nationwide survey of capstone courses was conducted in 1994 in an effort to better understand current practices at the time [1]. This was followed in 2005 by another nationwide survey [2] using many of the same questions to update the data and also to capture trends over time; the 2005 survey repeated many of the questions from 1994, and added some new quantitative and open-ended response questions.

Efforts to capture capstone practices have continued since 2005. A 2009 survey [3] included many of the quantitative logistical questions from 1994 and 2005 for comparative purposes, but extended the survey to include faculty experiences and opinions about capstone design pedagogy. Additional surveys across multiple institutions and capstone programs have been conducted by a variety of researchers on topics such as assessment [4], teaching load and funding [5], content in capstone design courses [6], capstone design problem statements [7], and technical design reviews [8], for example. Other researchers have focused their surveys on specific engineering disciplines [9, 10]. A nascent initiative to build an online capstone design community [11] also contributes to sharing capstone practices among capstone educators. The 2015 capstone design survey marks the official continuation of the decennial data collection effort. The 2015 survey reprised most of the questions from 1994 and 2005 augmented by a number of new multiple choice and open-ended questions, informed by the other recent surveys and conversations at capstone design conference sessions.

The data from the 2015 capstone design survey have been documented in various forms. Some of the quantitative results from the 2015 data were detailed in a short paper in the 2016 Capstone Design Conference proceedings [12]. The open-ended responses were discussed separately in a full-length paper in the 2016 ASEE proceedings [13]. The combined quantitative and qualitative data, plus some longitudinal and disciplinary comparisons were presented in the keynote address at the 2016 Capstone Design Conference [14]. This paper presents the comprehensive results of the 2015 capstone design survey, drawing from the previous two papers and the keynote address, and including comparisons across the 1994 and 2005 surveys and across disciplines. This documentation and the results of all the decennial surveys collectively are an important step towards understanding,

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assessing, and ultimately improving engineering capstone design education.

2. Methodology

The 2015 capstone survey included eleven main sections with a combination of multiple choice, fill-in-the-blank, and open response questions related to capstone course logistics, pedagogy, projects and teams, faculty, students, funding, and sponsors, among others. The collection of questions was informed heavily by the previous nationwide and focused surveys referenced above, as well as discussions at previous capstone design conferences. A PDF of the full survey is available on the CDHub 2.0 website: http://cdhub2.org/links/capstonesurveys/

The survey was implemented using SurveyMonkey and sent via email to the department chairs of all ABET-accredited engineering and engineering technology programs [15], the ASEE DEED (Design in Engineering Education Division) monthly newsletter, and the Capstone Design Community mailing list. Recipients were asked to take the survey themselves if they were in charge of capstone design and/or to forward it to their capstone design colleagues. The survey was officially open during the month of February 2015, and responses were accepted through mid-March. A total of 522 respondents, representing 464 distinct departments at 256 institutions, participated in the survey; all but two of these respondents had a capstone design course.

The results of the online survey (responses plus comments) were compiled and processed electronically. The approach used for analyzing the open-ended responses followed an open coding and integration methodology [16]. For each question, at least two authors independently read all responses and identified recurring content themes. All three authors compared, clarified, and consolidated the two separate lists into a single list of content themes. Two authors then independently coded the responses for the given question using the consolidated content themes. After working independently, the authors compared their resulting coding, discussed any discrepancies, and determined a final coding for each response; in many cases, responses were coded to more than one content theme. Then all three authors collaborated to group the content themes into broader categories for reporting and discussion. This process was repeated separately for each question.

3. Results and discussion

This section details and discusses the results of the 2015 survey, both in general and divided by discipline. Where possible, the 2015 data are also presented in comparison with the relevant 1994 and 2005 data. The results and discussion are organized into eight main sub-sections roughly following the order in which these topics were asked in the survey instrument itself: respondent profile, course logistics, pedagogy, faculty and students, projects and teams, expenses and funding, sponsors, and experience/opinion.

3.1 Respondent profile

The 522 survey respondents to the 2015 survey represent 464 distinct departments from 256 institutions. Fig. 1 shows the respondents sorted by the closest disciplinary grouping, with each respondent mapped to only one group. In many cases, the grouping represents more than just the listed discipline(s). For example, "Chemical" includes pure chemical engineering respondents, as well as chemical and biomolecular, and chemical and biological. Similarly, some of the "Civil/Environmental" departments include architecture or surveying, and some of the "Industrial" departments include manufacturing or systems. The "Multidisciplinary" grouping includes all respondents whose capstone program spanned more than one listed disciplinary

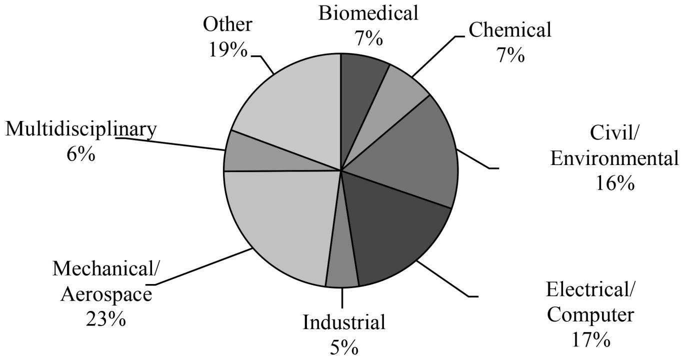


Fig. 1. Survey Respondents by Departmental Grouping (2015 Data, n = 522).

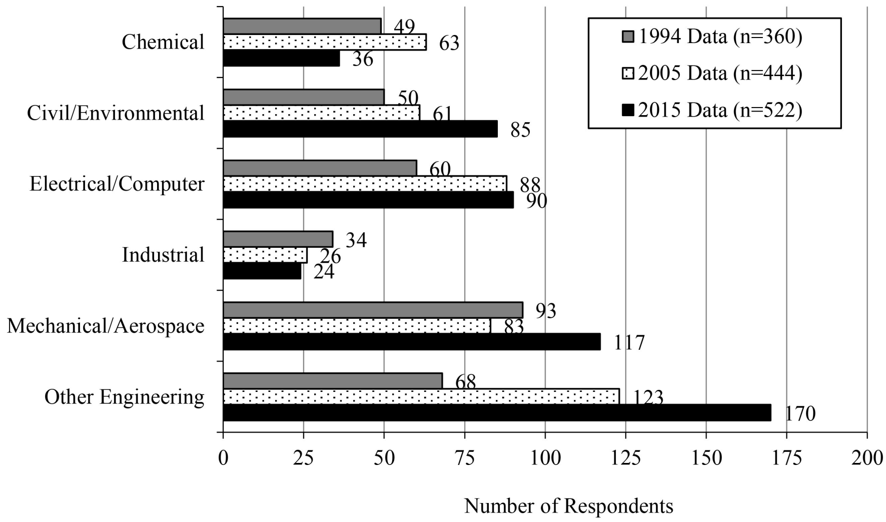


Fig. 2. Survey Respondents by Discipline (Longitudinal Data).

grouping, such as a combination of mechanical, materials, and electrical engineering. The "Other Engineering" grouping includes other specific disciplines such as agricultural, geological, materials, mining, nuclear, petroleum, and general engineering. The distribution shown in Fig. 1 matches fairly closely to the distribution of ABET accredited programs as of fall 2014 [15], though with under-representation of Electrical/Computer programs (17% vs 29% in ABET).

Figure 2 shows the 2015 disciplinary data in comparison with 1994 and 2005 respondent data. In all cases, respondents are mapped to only one group. Note that since the 1994 survey reported on a smaller number of disciplinary groupings, the "Biomedical" and "Multidisciplinary" data from 2015 have been included in "Other Engineering" for ease of comparison. In all three surveys, mechanical/aerospace disciplines had the largest set of respondents, followed by electrical/computer, and civil/environmental. The continued growth in "Other Engineering" in 2015 is likely due in part to the increased number of biomedical and multidisciplinary engineering programs not represented in earlier surveys (see Table 1 discussed below).

The overlap between the 1994 and 2005 surveys averaged 28% across departments [2]. Interestingly, this overlap value held fairly steady in 2015 as well: 26% of 1994 respondents and 25% of 2005 respondents also responded to the 2015 survey. A total of 38 respondents (11% of 1994 data) responded to all three surveys! Given that each of the surveys was sent to large target populations and that new capstone courses have been created and modified over time, this level of overlap is substantial and demonstrates the willingness of engineering faculty nationwide to contribute to such research efforts.

Figure 3 shows the age of capstone programs for the 2015 data. The data reveal a wide range of ages, spanning from programs that had just started to others more than 50 years old. A third of the respondents had capstone programs that had

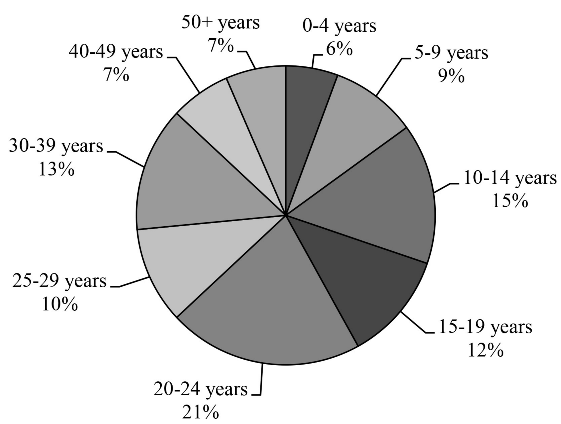


Fig. 3. Age of Capstone Course (2015 Data, n = 460).

Table 1. Age of Capstone Course by Discipline (2015 Data)

	Percent of Respondents*							
Age	BME (n=35)	ChE (n=31)	CEE (n=77)	EECS (n=76)	IE (n=23)	MAE (n=109)	MULTI (n=28)	OTHER (n=81)
0-4 years	0	3	8	5	0	8	11	4
5-9 years	26	3	4	4	9	6	21	16
10-14 years	23	6	16	17	4	13	21	17
15-19 years	17	0	16	22	13	7	14	5
20-24 years	14	6	26	22	26	17	21	28
25-29 years	11	6	13	12	9	13	0	9
30-39 years	9	26	12	7	26	20	7	9
40-49 years	0	13	4	9	13	8	0	5
50+ years	0	35	3	1	0	8	4	7

* Greyscale shading increases in 8% increments.

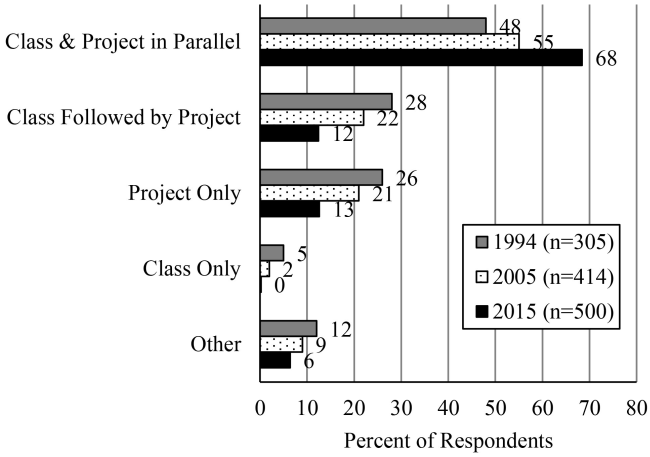


Fig. 4. Capstone Course Structure and Sequence (Longitudinal Data).

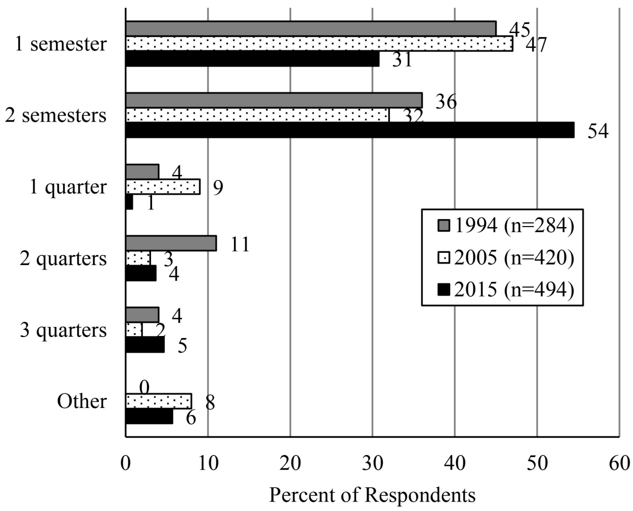


Fig. 5. Capstone Course Duration (Longitudinal Data).

existed for 25 years or more, with the oldest respondent reporting 126 years. It is important to note that 2015 survey question was worded "How many years has your capstone design course existed?" This marked an intentional change from the 2005 wording ("How long has this course been in existence in its present form?") since capstone courses that had changed significantly in the recent past may have skewed previous responses. As a result of this wording change, however, longitudinal comparisons cannot be made regarding age.

Table 1 shows the 2015 age data divided by discipline. The greyscale shading in the table cells (which includes five levels: white, three shades of grey, and black) increases in 8% increments, for ease of visibility. (Subsequent tables in this paper have a

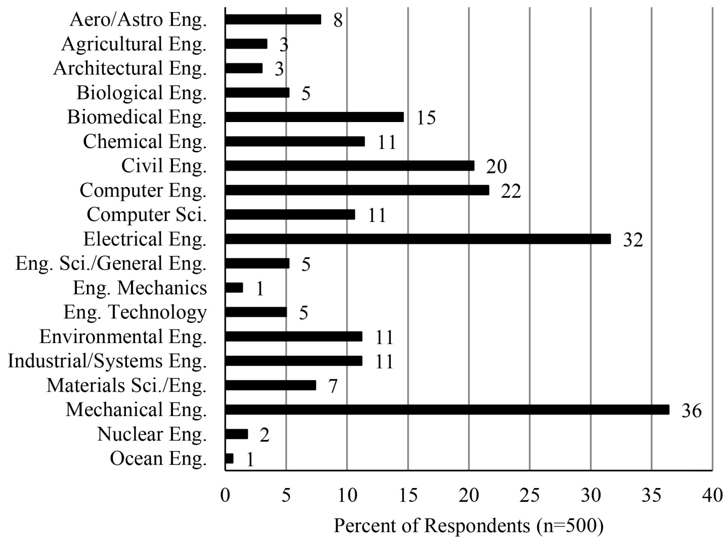


Fig. 6. Disciplines Involved in Capstone Design Courses (2015 Data).

similar greyscale shading, but increments tailored to the data in the table.) As is clear from Table 1, most departmental groupings have a fairly normal distribution of ages, with the exception of the relatively newer biomedical and the relatively older chemical engineering capstone courses.

3.2 Course logistics

Figure 4 shows the structure and sequence of capstone design courses. The vast majority of respondents ran the class and project in parallel, as they had done previously. No 2015 respondents indicated "Class Only", meaning there was no project. The "Other" responses in 2015 included a combination of different options at different times or a variable course structure.

Figure 5 shows the duration of capstone design courses. More than half of the 2015 respondents had a 2-semester capstone design course, which is a sizable increase from previous years. In addition, the 2015 data show a drop in both 1-semester and 1-quarter durations. The "Other" responses in 2015 mostly reflected even longer durations, including 2–3 trimesters, 4 quarters, and even 3–4 semesters. Collectively, the data suggest that the length of capstone courses is increasing.

The 2015 survey asked respondents "What departments (faculty and/or students) are part of

Table 2. Categories and Content Themes Regarding Design Prerequisites (2015 Data)

Design Prerequisites	Percent of Respondents* (n=312)	Content Themes
Specific Courses	42	specific elective courses and labs; department specific courses; sequence of design courses; other design course(s)
Specific Engineering Topics	29	machine design; design components in other courses; CAD; mechanical design; thermal design; software engineering, software design; design and manufacturing; simulation/testing; design theory, methods; experimental methods; construction management; component design; system design; modeling with architectural drawings; product design
None	20	none/nothing specific
Specific Years	17	freshman design/intro to design; junior design; sophomore design; senior design
Criteria-Based	10	senior standing or minimum # of credits
Other Topics	5	economics; project management; technical communications, technical writing; math; physics
Varies	4	varies by department/major
Most/All	4	most or all elective courses; all core courses through 300 level; all core courses
General Yes	3	(no themes – response affirms that there are design prerequisites)

* Greyscale shading increases in 9% increments.

your capstone design course? Select all that apply." The checklist included a wide range of engineering disciplines in alphabetical order, as shown in Fig. 6. Write-in responses to the "Other" option included additional engineering disciplines such as geological engineering, manufacturing engineering, mining engineering, petroleum engineering, and software engineering, but the response rates for each of these disciplines were 1% or less. The checklist also included multiple non-engineering disciplines: art/architecture/design, business/marketing, communication, health/medical/nursing, humanities, mathematics/statistics, natural sciences, and social sciences. The response rate for "Business/Marketing" was 4%, but for all others was 2% or less. Of the 500 respondents, 262 (52%) included faculty and/or students from at least two different disciplines in their capstone courses; 57 (11%) had at least five different disciplines represented.

One of the open-ended questions on the 2015 survey asked respondents "What design courses do you require as prerequisites for capstone design?" The responses to this question grouped into nine categories, as shown in Table 2. The most common type of response regarding design prerequisites from participants was a list of specific courses. Of those answers, nearly half (n = 69) were specific elective courses or labs, with the remaining responses distributed fairly equally. Heat transfer, circuits, and fluids were some of the more popular examples of specific elective courses provided by respondents. Specific engineering *topics* were listed as design prerequisites by nearly a third of respondents (n = 91), with machine design counting for a third of the responses (n = 30), likely a result of the sizable portion of respondents from mechanical engineering programs. About one-fifth of the respondents (n = 61) noted that they had no design prerequisites for capstone design.

3.3 Pedagogy

Table 3 shows the results from the 2015 survey, with topics covered specifically in lecture (L), in an individual assignment (IA), as part of the team project (TP), or not covered (NC). Capstone design courses clearly cover a lot of topics, with the majority of the listed topics covered by the majority of respondents either as part of the team project or in lecture. Beyond the list of topics provided, 184 respondents also provided more than 100 distinct write-in topics. Most common were engineering economics/financial analysis, design for X, professional preparation and licensure, and safety/liability.

Table 4 displays the top five topics covered throughout the 1994, 2005, and 2015 surveys. The data, which have changed very little over the years, reveal a notable emphasis on professional skills.

An oft-discussed topic at the biannual capstone design conferences is that of product versus process in capstone design. As such, the 2015 survey asked respondents "How do you balance product versus process in your capstone design projects?" Responses were coded into seven distinct categories based on numerical value provided (51–74% = "emphasis", 75–94% = "heavy emphasis", 95–100% = "all") or interpretation of the response by the researchers based on wording and adjectives. While more than 208 responses were received, only

Table 3. Topics Covered in Capstone Design (2015 Data, n = number of respondents)

		% of Respondents*			
Category	n	L	IA	TP	NC
Analysis tools	450	45	25	83	9
CAD design/layout	440	23	18	67	28
Concept generation	453	62	23	80	7
Concept selection	451	61	24	81	7
Creativity/prob. solving	462	53	24	80	6
Decision making	458	58	19	80	7
Functional Specs	455	56	24	77	12
Engineering ethics	455	69	30	45	12
Intellectual property	440	51	12	33	37
Leadership	443	47	14	64	19
Optimization	430	36	12	57	32
Oral communication	469	57	29	89	1
Project management	468	67	26	89	2
Prototyping, testing	445	41	16	71	22
Sketching	422	18	14	46	44
Standards/regulations	448	59	17	70	10
Sustainability	434	44	13	53	27
Teamwork	463	57	21	81	5
Written communication	472	56	42	91	1

* Greyscale shading increases in 9% increments.

Table 4. Top Five Topics Covered in Capstone Design (Longitudinal Data)

1994	2005	2015 Lecture	2015 Overall
Oral communication	Written communication	Engineering ethics	Written communication
Concept generation	Oral communication	Project planning and scheduling	Project planning and scheduling
Teamwork	Engineering ethics	Concept generation/selection	Oral communication
Planning/scheduling	Project planning	Standards and regulations	Concept generation/selection
Engineering ethics	Decision making	Decision making	Team building/teamwork

Table 5. Balance between Product and Process in Capstone Design (2015 Data)

Category	Percent of Respondents* (n=208)	Representative Quote
All product	1	"Product is key!"
Heavy emphasis on product	5	"We focus most on the product and very little on processes."
Emphasis on product	8	"Probably 60% on the product and 40 % on the process, especially formal processes"
Equally, both important	34	"The final product is the result of the process so they have to balance."
Emphasis on process	32	"Process wins out, but product usually follows for a good process."
Heavy emphasis on process	13	">80% process which is consistent with the types of jobs available for and skills expected for our graduating engineers"
All process	6	"We typically don't build the real products, as the system costs millions to construct. Hence, we focus on the design process."

* Greyscale shading increases in 7% increments.

those that could be definitively coded are included here. Table 5 shows the results of the coding, with a representative quote from each category. Although there are capstone programs that focused solely on product or solely on process, the majority of respondents either weighed the two equally or emphasized process.

Figure 7 shows the distribution of product versus process within specific departments. Chemical engineering shows the starkest contrast, with all respon-

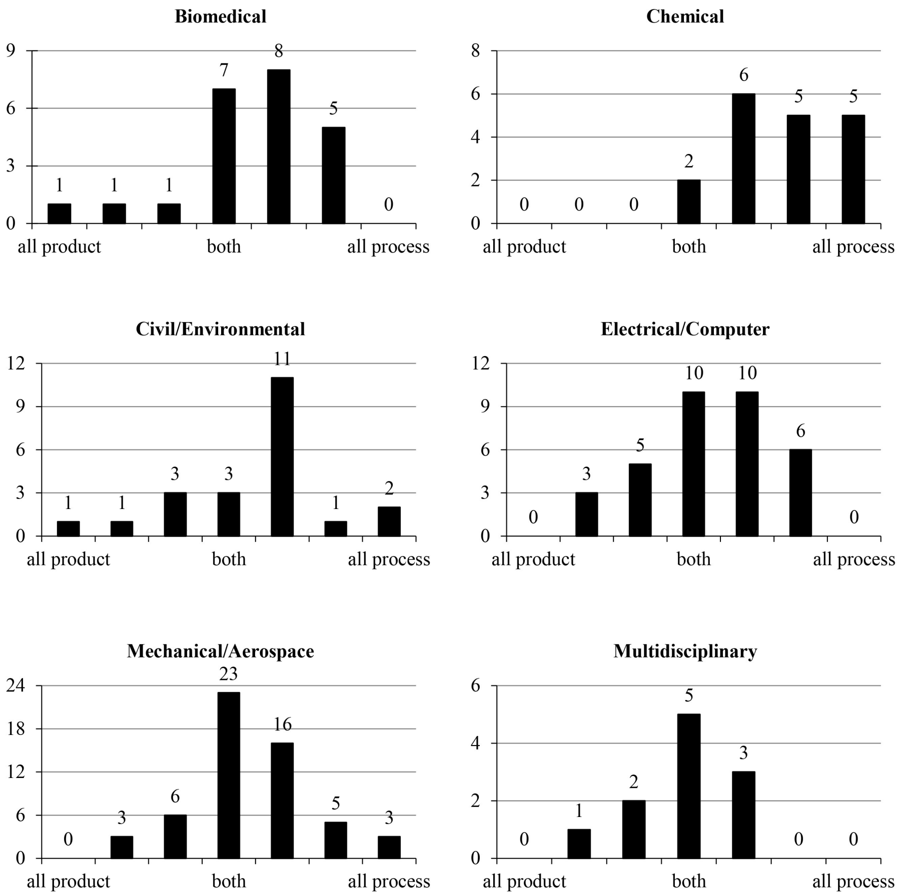


Fig. 7. Product vs. Process by Discipline (2015 Data, y-axis = Number of Respondents).

Table 6. Evaluators of Students' Work (2015 Data)

Evaluator	Percent of Respondents*				
	Have high input on course grade	Have moderate input on course grade	Have limited input on course grade	Evaluate projects, don't contribute to course grade	No role at all
Course Instructors (n=467)	83	8	5	2	2
Project Advisors/Coaches (n=462)	36	26	14	11	14
Industry Liaisons (n=460)	8	17	24	28	24
Other Department Faculty (n=457)	5	12	25	21	37
Students (n=455)	3	14	36	22	25
Department Advisory Board (n=454)	2	6	12	20	61
National Competition Judges (n=450)	1	1	2	12	83

* Greyscale shading increases in 18% increments.

Table 7. Evaluation of Deliverables (2015 Data)

Deliverable	Percent of Respondents*			
	Major role in evaluation	Moderate role in evaluation	Minor role in evaluation	Not considered in evaluation
Final written report (n=469)	77	20	2	0
Final oral presentation (n=468)	63	29	7	1
Final product (n=460)	62	24	5	8
Design process (n=464)	41	44	13	3
Mid-course reports (n=462)	23	48	21	8
Mid-course presentations (n=463)	18	45	25	12
Design reviews (n=464)	17	41	29	13
Individual assignments (n=458)	10	24	37	29
Logbooks (n=458)	9	17	27	48
Peer feedback (n=459)	8	33	40	18
Hours spent on project (n=458)	6	18	22	54
Quizzes/exams (n=455)	6	12	19	62
Business plan (n=453)	4	9	25	62

* Greyscale shading increases in 16% increments.

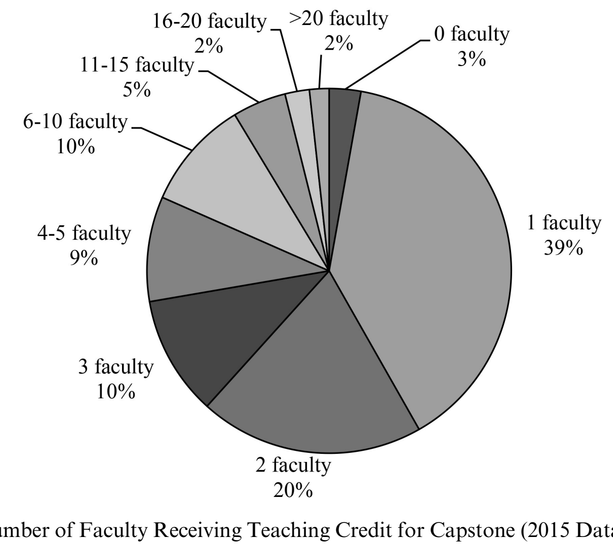


Fig. 8. Number of Faculty Receiving Teaching Credit for Capstone (2015 Data, n = 462).

dents either favoring process or an even split between the two. For chemical engineering projects, it is often the case that the process itself is the product, therefore the question may not have been clear or seemed relevant. The emphasis on process can also be seen, although to a lesser extent, in biomedical and civil/environmental engineering departments, perhaps in part because projects within civil engineering departments are on a scale too large to be produced by students, and the process in biomedical engineering is itself highly regulated.

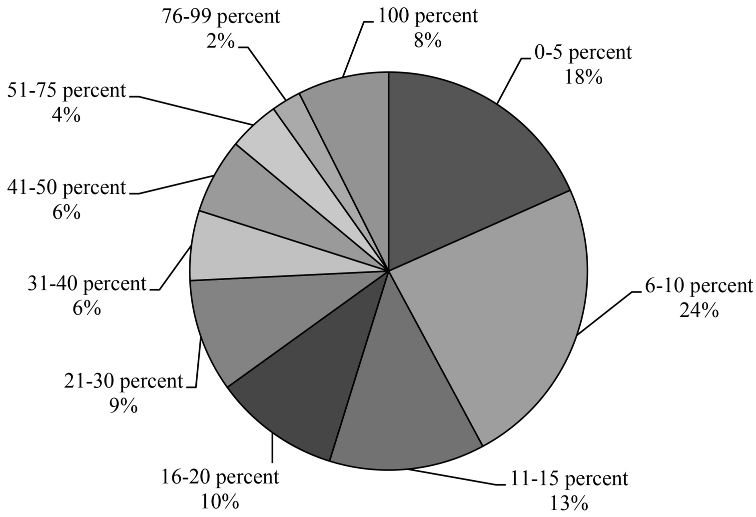


Fig. 9. Percent of Faculty in Department Receiving Teaching Credit for Capstone (2015 Data, n = 458).

Table 8. Percent of Faculty in Department Receiving Teaching Credit for Capstone, by Discipline (2015 Data)

	Percent of Faculty		
Discipline	**Mean**	**Median**	**[Min, Max]**
Biomedical (n=34)	26	15	[2, 100]
Chemical (n=31)	19	14	[5, 100]
Civil/Environmental (n=74)	27	16	[0, 100]
Electrical/Computer (n=77)	22	9	[0, 100]
Industrial (n=22)	37	13	[3, 100]
Mechanical/Aerospace (n=109)	25	13	[0, 100]
Multidisciplinary (n=26)	34	17	[0, 100]
Other (n=86)	24	14	[0, 100]

As shown in Tables 6 and 7, evaluation of student performance was informed by many people and based on many different types of work. Course instructors and project coaches had the highest level of input on grades in 2015, whereas departmental advisory board members and competition judges had a limited role if any. The final report, final oral presentation, and final product each had the biggest role in evaluation among 2015 respondents. The design process, interim work and design reviews were of similar importance in assigning grades. A large majority of respondents (81%) also indicated that peer feedback played at least a minor role. When asked how grades were assigned in capstone design, 90% of 469 respondents selected "Individually assigned based on both individual and team performance."

3.4 Faculty and students

Figure 8 shows the number of faculty receiving teaching credit for capstone design. The 2005 survey also queried about faculty in capstone, but in terms of "faculty involvement" more generally rather than "teaching credit" specifically, so the two sets of data are not directly comparable. As is evident from the 2015 data, the majority of programs provided teaching credit to just one or two faculty members, though in some programs 11 or more faculty members all earned teaching credit for their involvement in capstone design. It is worth noting that 90% of 459 respondents in 2015 marked that capstone is treated as "normal teaching activity" when compared with other activities that provide evidence for promotion and tenure.

Also of interest regarding faculty involvement is the percentage of faculty in a given department who received teaching credit, as shown in Fig. 9. Although the majority of programs provided teaching credit to 20% or fewer of the faculty in their department, it is worth noting the 8% of programs in which all 100% of faculty received teaching credit for capstone design, demonstrating department-wide investment.

Table 8 depicts the percentage of faculty receiving teaching credit divided by discipline. Although there was some spread in the mean values, the median values were more similar to each other, suggesting little difference across discipline or age of program. Also, all disciplinary and program age categories had a range of respondent data, from 0 to 3% as the minimum, to 100% in all cases.

Responses to the open-ended question "If you involve multiple faculty in your capstone design course, how do you structure and manage their

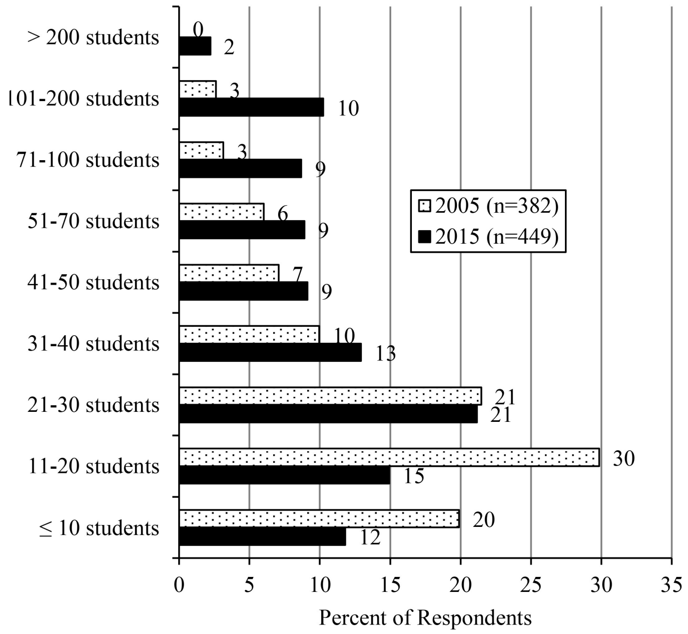


Fig. 10. Number of Students per Capstone Course Cycle (Longitudinal Data)

involvement?'' suggested that respondents (n = 211) had a variety of ways of involving multiple faculty. The most common approach (n = 86) was some sort of shared responsibility, such as a tiered system with a primary course instructor and additional faculty coaches, or a true co-teaching model. Respondents also noted various strategies for faculty/team interaction (n = 76), such as faculty mentors and faculty as customer/client. Some respondents (n = 46) listed ways in which faculty were involved in a minor role, such as evaluating the final presentation or product, serving as technical consultants, or providing a guest lecture.

Figure 10 shows the number of students per capstone design course cycle. Not surprisingly, given the range of institutions and departments represented, the 2005 and 2015 data include a wide range of student numbers, from classes with fewer than 10 students to those with more than 200 at a time. Of particular interest, however, is the fact that student numbers appear to be increasing: the median bracket in 2015 is higher than that in 2005. Capstone design is aptly also known as ''senior design'': according to 2015 data, 88% of the 463 respondents noted their capstone design students were undergraduate seniors, whereas 7% noted a mix of undergraduate seniors and juniors, and only 3% of respondents had a mix of undergraduate seniors and graduate students.

Table 9 provides the 2015 student numbers divided by discipline. All disciplines had a wide spread of responses, but overall, mechanical/aerospace and multidisciplinary capstone courses tended to have more students, whereas electrical/computer, industrial, and ''other'' engineering disciplines (agricultural, materials, general engineer-

Table 9. Number of Students per Capstone Course Cycle by Discipline (2015 Data)

	Percent of Respondents*							
Number of Students	BME (n=33)	ChE (n=28)	CEE (n=75)	EECS (n=77)	IE (n=22)	MAE (n=106)	MULTI (n=25)	OTHER (n=81)
≤10	6	7	12	9	23	9	8	20
11-20	12	11	16	26	9	7	4	21
21-30	18	21	31	27	32	15	8	17
31-40	9	25	13	10	18	11	12	14
41-50	15	7	7	10	5	11	4	9
51-70	21	14	7	8	0	10	0	9
71-100	12	4	8	6	14	10	24	4
101-200	6	11	5	3	0	23	16	7
> 200	0	0	1	0	0	3	24	0

* Greyscale shading increases in 7% increments.

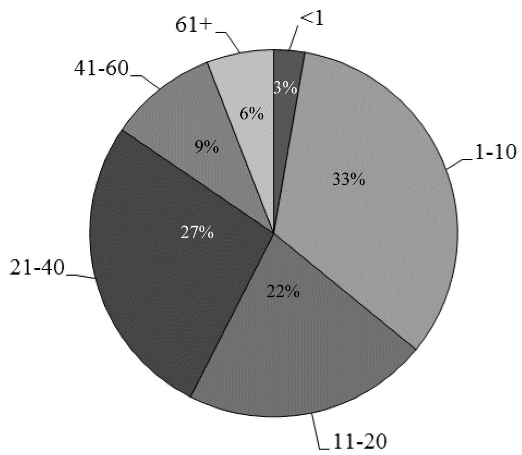


Fig. 11. Student/Faculty Ratio (2015 Data, n = 440).

Table 10. Student/Faculty Ratio by Discipline (2015 Data)

	Percent of Respondents*							
Student/ Faculty Ratio	BME (n=33)	ChE (n=30)	CEE (n=74)	EECS (n=74)	IE (n=22)	MAE (n=106)	MULTI (n=23)	OTHER (n=78)
<1	0	0	4	4	5	3	0	1
1-10	21	13	42	34	36	26	35	46
11-20	33	30	16	18	23	20	26	23
21-40	33	40	23	30	23	27	26	22
41-60	12	7	8	8	5	15	9	6
61+	0	10	7	7	9	8	4	1

* Greyscale shading increases in 10% increments.

ing, etc.) tended to have smaller capstone courses on average.

Combining the number of faculty receiving teaching credit with the number of students per capstone course cycle leads to data for student/faculty ratio, as shown in Fig. 11. While student/faculty ratios of 20:1 or less were most common, some programs had ratios exceeding 60, with one program topping out at 170! Table 10 provides the student/faculty ratio data divided by discipline. These data are more similar across disciplines than those of the student numbers, but civil/environmental and "other" engineering disciplines had the lowest average student/faculty ratios, and chemical engineering disciplines had the highest.

Figure 12 shows the average number of hours students are expected to spend on their capstone design course each week. The median bracket in 2005 was 4–6 hours, but that increased to 7–9 hours in 2015, suggesting that expectations for student time commitment have increased. Some of the accompanying comments in 2015 noted that the

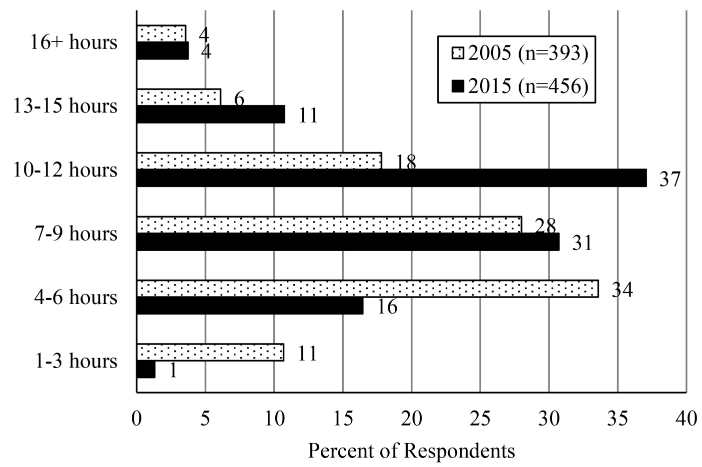


Fig. 12. Average Expected Student Hours per Week Working on Project (Longitudinal Data).

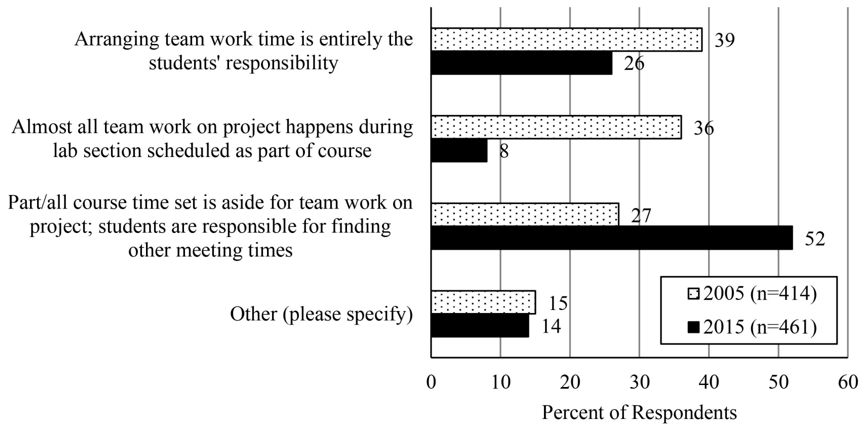


Fig. 13. Approaches to Ensure Student Work Time (Longitudinal Data).

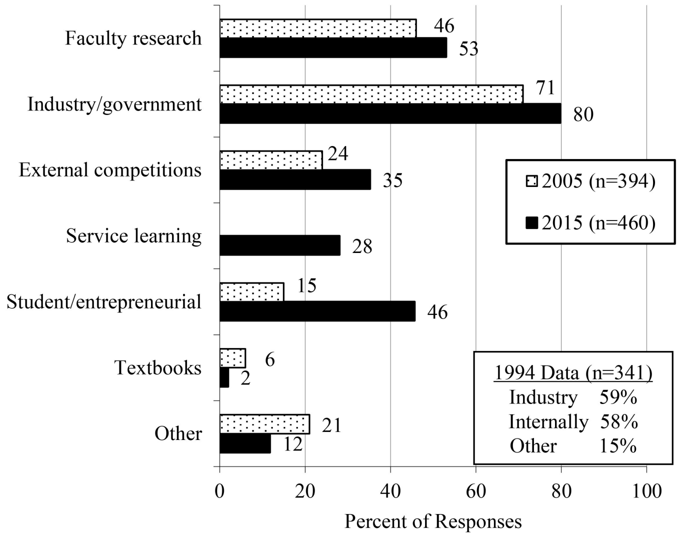


Fig. 14. Sources of Capstone Projects (Longitudinal Data).

expectation varied at different times (i.e. fall vs. spring). Other respondents noted that students were expected to spend "*as long as it takes*".

A related question on both the 2005 and 2015 surveys asked about how the capstone program ensures that student teams are able to meet; the data are shown in Fig. 13. Although responses were more evenly split between several options in 2005, the majority of 2015 respondents employed the hybrid model where some/all class time was provided to start but students were responsible for finding other times outside of class. The most common write-in response—in both 2015 and 2005—from respondents who selected "Other" was that student teams had weekly meetings with their faculty coach.

3.5 Projects and teams

Figure 14 shows the range of sources of capstone design projects across survey years. Note: the 1994 data were reported only as "Industry", "Internally", and "Other", so they are shown in a separate box. The most popular source for both 2015 and 2005 was industry/government, followed by faculty research. The 2015 data indicate an increase in entrepreneurial projects, as well as the emergence of service learning projects. The "Service Learning" option was provided on only the 2015 survey, so there is no longitudinal comparison. Sources in the "Other" category for 2015 included clinicians and instructor ideas.

Table 11 breaks down the project source data from the 2015 survey by discipline; the numbers in the table indicate percent of respondents that indicated having at least one project from the project source category. Industry and government were the most common project source for most departments, in particular for nearly all industrial engineering and multidisciplinary engineering respondents. Projects based on faculty research were especially prominent in biomedical, electrical/computer, and mechanical/aerospace disciplines. Projects from

Table 11. Source of Capstone Projects by Discipline (2015 Data)

	Percent of Respondents*							
Project Sources	BME (n=34)	ChE (n=31)	CEE (n=74)	EECS (n=77)	IE (n=22)	MAE (n=109)	MULTI (n=27)	OTHER (n=86)
Industry/government	71	71	84	68	95	87	96	78
Faculty research	74	39	15	75	14	64	52	60
External competitions	35	55	18	34	5	63	26	22
Service learning	35	10	34	23	5	36	30	28
Student/entrepreneurial	47	35	16	77	9	58	41	43
Textbooks	0	16	1	3	0	2	0	0
Other	32	19	16	4	0	9	7	8

* Greyscale shading increases in 20% increments.

Table 12. Strategies for Finding Capstone Projects (2015 Data)

Project Source	Percent of Respondents* (n=321)	Content Themes
External Contacts	54	local and regional industries; alumni; industrial advisory board; previous sponsors; connections in general; personal contacts of capstone instructor; faculty and department contacts; development office; word of mouth; student contacts; co-op and internship contacts; clinicians; other university's capstone project sponsors
Internal Sources	28	student-proposed; faculty research and ideas; brainstorming; on-campus projects
Marketing	26	solicitation and networking; advertising; internet searches
Prefab/ready to go	9	competitions; repeat previous projects; textbooks
Criteria-based	7	global trends and industry needs; multidisciplinary groups
Magnet	5	approached externally; reputation
Who Finds	4	dedicated capstone personnel; leave to faculty mentor
Development/grants	3	departmental/institutional support (business incubator, development office, university relations)
Extreme	3	no coordinate strategy; anything and everything
Events-based	2	demo day or project day; attend career day; conferences

* Greyscale shading increases in 12% increments.

competitions were most often found in chemical and mechanical/aerospace disciplines, and entrepreneurial projects are common in electrical/computer engineering disciplines specifically. Nearly a third of biomedical, civil/environmental, and mechanical/aerospace disciplines sourced at least some of their projects from service learning opportunities. It is also worth noting that 32% of biomedical respondents indicated that some of their projects were from other categories, including clinicians.

The 2015 survey asked respondents the open-ended question "What strategies do you use for finding capstone design projects?" The data can be clustered in nine categories, as shown in Table 12. Over half of responses (n = 173) utilized external contacts as a source of finding projects. Of those, about a third of respondents (n = 50) mentioned local and regional industries: "*Keep sponsors located within a 90 mile radius.*" A comparable number of comments (n = 49) remarked that alumni were a significant source of projects: "*Our alumni network is our best resource.*" Many responses (n = 92) also pointed out internal sources of projects, with student-proposed ideas making up a majority (n = 58). One respondent said, "*Have the students go out and talk to people to identify a real problem and then solve it.*"

Following up on the question about finding capstone projects, the 2015 survey also asked about what criteria respondents use to select/vet capstone design projects. The 311 responses to this question can be grouped into ten main categories, as shown in Table 13; most comments mapped to more than one category and more than one content theme within a category, indicating that respondents had multiple criteria for selecting/vetting projects.

Half the responses map to the category of "good fit", suggesting that ensuring a good fit between the project and various parameters of the capstone program was important to many respondents. Within this category, the majority of responses focused on appropriate scope and complexity for course duration and team size (n = 94), as shown in the response, "*Project must be of sufficient complexity, sufficient quantity of work for 3–5 people.*" In addition to specific criteria for selecting projects, about a quarter of respondents (n = 81) also provided information regarding who does the

Table 13. Criteria for Selecting/Vetting Projects (2015 Data)

Criteria	Percent of Respondents* (n=311)	Content Themes
Good Fit	50	appropriate scope and complexity for course duration and team size; appropriate rigor and technical challenge given student abilities; matched to curriculum and disciplines/departments involved; satisfies academic requirements; suitable for available facilities and resources; incorporates multiple disciplines, fairness across disciplines; geographic location, local and accessible
Who Chooses	26	capstone instructor discretion and experience; faculty review; student decision; technical merit matrix
Experience Opportunities	18	opportunity to build prototype; open-ended; enables student learning experience; allows creativity and innovation
Baseline Content	16	includes design; includes engineering analysis; includes hardware and/or software component; requires engineering and non-engineering knowledge
Baseline Logistics	16	sufficient funding; available data and background information; has clear design requirements and goals; satisfies ABET; does not require research; not illegal or unsafe; can be evaluated; students can own IP
Sponsor Relations	12	available and approachable sponsor liaisons; credibility of sponsor; track record or previous collaboration with company; not on company critical path
Interesting	12	of interest to students; of interest to faculty; connection to faculty research or expertise; institutional visibility
Real World	11	value to client - not contrived; societal impact; not already available commercially; representative of current work in industry
Success	6	probability of success; doable
Not/Varies	4	informal or no process; variety across project slate; varies based on department

* Greyscale shading increases in 10% increments.

selecting, with most mapping to either instructor discretion (n = 36) or faculty review (n = 36), with responses such as "*Faculty review all available options and select projects of proper scope. Students then can choose from a pre-selected list.*"

Figure 15 shows the number of capstone projects per course cycle for the 2015 data. The responses are well distributed from one project to 40+ projects: just over 50% of respondents had fewer than 10 projects per course cycle, and just over 25% of respondents had more than 15 projects per course cycle. The highest reported response from the 2015 survey was 100 projects in a single capstone course cycle. Figure 16 shows the same data in comparison with that of previous surveys, albeit with larger ranges within each category (e.g. "6–10" instead of multiple smaller categories) per the question wording on previous surveys. The number of projects per capstone course cycle has increased in the past decade. In 2005, the mean and median number of projects were 8.1 and 5, respectively; in 2015 these numbers increased to 12.4 and 9, respectively.

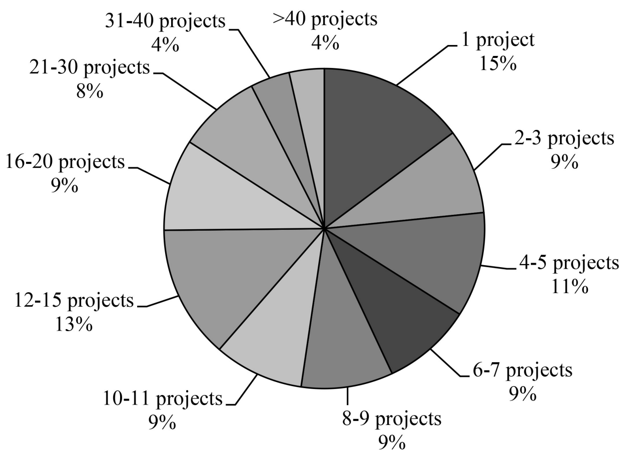


Fig. 15. Number of Projects per Capstone Course Cycle (2015 Data, n = 453).

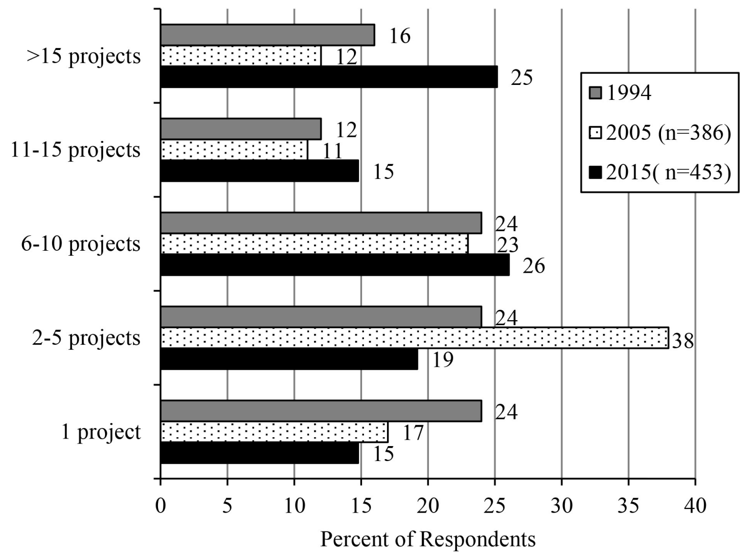


Fig. 16. Number of Projects per Capstone Course Cycle (Longitudinal Data, n is unknown for 1994).

Table 14. Number of Projects per Capstone Course Cycle by Discipline (2015 Data)

	Percent of Respondents*							
Number of Projects	BME (n=34)	ChE (n=31)	CEE (n=73)	EECS (n=77)	IE (n=22)	MAE (n=108)	MULTI (n=26)	OTHER (n=82)
1 project	3	26	36	12	5	7	4	16
2-5 projects	6	29	21	19	14	14	19	28
6-10 projects	21	29	29	30	41	26	12	22
11-15 projects	32	13	7	23	9	13	15	11
>15 projects	38	3	8	16	32	40	50	23

* Greyscale shading increases in 10% increments.

Table 14 shows the number of capstone projects per course cycle from the 2015 data by discipline, using the same numerical brackets as in Fig. 16. The data indicate that there was a fairly even spread across most disciplines. Half of the multidisciplinary respondents, however, had more than 15 projects per course. And at the other end of the spectrum, civil/environmental engineering respondents were most likely to have a single project per course.

Figure 17 shows the number of students per team from the 2015 survey data. The categories represent the average number of students per team, and the numbers in brackets represent the smallest minimum and largest maximum within each category. More than 75% of respondents had between 3 and 5

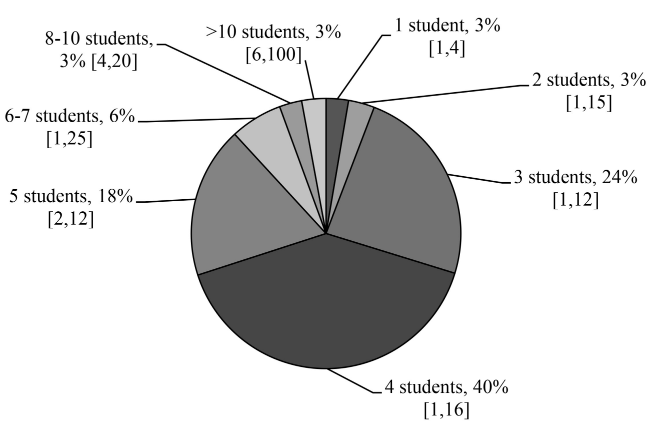
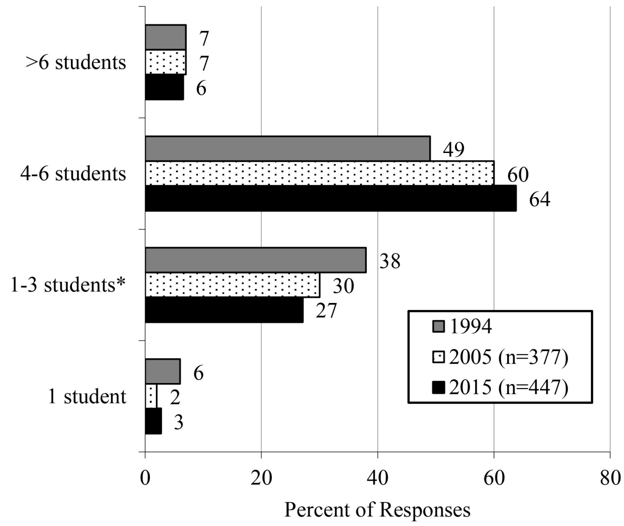


Fig. 17. Number of Students per Capstone Team (2015 Data, n = 447, with [min, max] for respondents in given student number range).

Table 15. Number of Students per Capstone Team by Discipline (2015 Data)

	Percent of Respondents*							
Team Size	BME (n=34)	ChE (n=31)	CEE (n=71)	EECS (n=75)	IE (n=21)	MAE (n=107)	MULTI (n=27)	OTHER (n=81)
1 student	3	0	3	4	10	0	4	4
2 students	3	3	1	5	5	0	0	7
3 students	47	23	7	41	57	12	4	27
4 students	35	61	49	37	19	41	26	38
5 students	9	13	17	9	5	30	41	14
6-7 students	3	0	10	1	0	8	22	5
8-10 students	0	0	6	1	0	5	0	2
>10 students	0	0	7	0	5	4	4	2

* Greyscale shading increases in 15% increments.



* In 1994, "1-3 students" was a specific choice.
In 2005, "1-3 students" refers to all responses > 1.5 and <3.5 students.
In 2015, "1-3 students" refers to an average of 2 or 3 students.

Fig. 18. Number of Students per Capstone Team (Longitudinal Data).

students per team, but a handful had team sizes exceeding 10 students per team. Respondents also reported on the number of teams assigned per project; in all three surveys, the majority response was one team per project (73% of n = 458 in 2015). However, some of these 2015 respondents also noted that occasionally they assigned two teams per project, especially when enrollment numbers warranted the change.

Table 15 shows the same student number data from 2015 sorted by discipline. For nearly all disciplines, the most common team size was 3 or 4 students, with the exception of multidisciplinary, which favored 5 students per team. Larger team sizes were a minority for all disciplines.

Figure 18 depicts team size data from all survey years and confirms that the overall distribution of the data is similar in all three data sets, with a slight increase in the 4–6 student bracket in 2015.

Figure 19 shows the methods for assigning students to capstone design teams. Many respondents chose more than one option, as evidenced by the fact that the sum of the data far exceeds 100%. The most common way to assign students to teams was student choice, followed by instructor choice and student skills. The category labeled "Other" includes write-in responses such as GPA, schedules, and CATME software [17].

3.6 Expenses and funding

Capstone design courses and projects have a number of different associated expenses, as shown in Figure 20. Project supplies, hardware, and software were the most commonly report expenses, noted by more than two-thirds of respondents in 2015. Some of the more common "Other" responses included external fabrication/analysis, personnel and summer salary, and respondents who noted that they had no expenses at all.

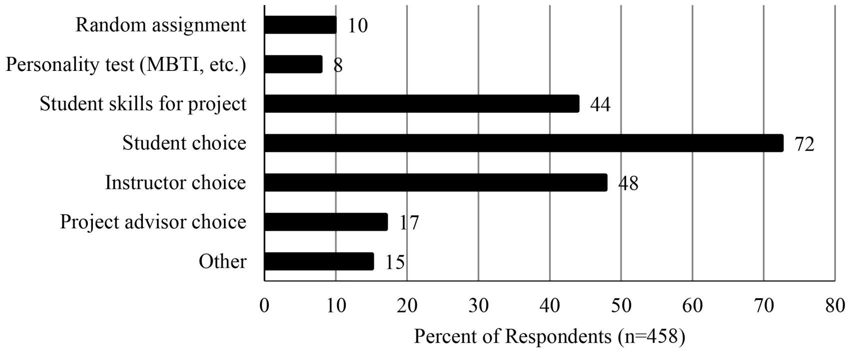


Fig. 19. Methods for Assigning Students to Capstone Teams (2015 Data).

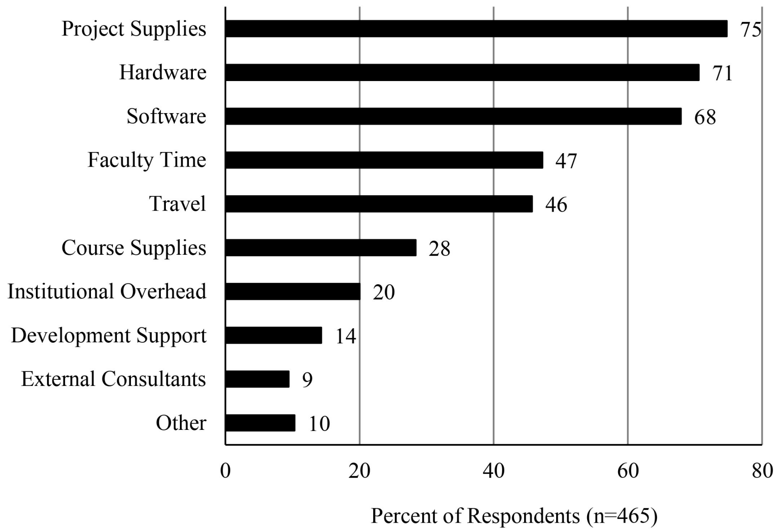


Fig. 20. Types of Expenses Associated with Capstone Projects and Course (2015 Data).

Table 16 shows the same expense type data from 2015, this time sorted by discipline. Project supplies and hardware were nearly universal expenses for biomedical, electrical/computer, mechanical/aerospace, and multidisciplinary engineering programs; only a third of chemical engineering programs had such expenses. Most EE/CS programs also, not surprisingly, had software expenses as well. Chemical engineering programs were more likely to spend funds on faculty time than were programs in other disciplines. Travel was an expense for 77% of the multidisciplinary engineering capstone programs, but for only 22% of EE/CS programs. Interestingly, about one in five responding civil/environmental engineering and multidisciplinary engineering capstone programs spent funds on external consultants, perhaps as mentors for the capstone design teams.

Following the question about types of expenses,

Table 16. Types of Expenses by Discipline (2015 Data)

	Percent of Respondents*							
Expense Type	BME (n=34)	ChE (n=31)	CEE (n=71)	EECS (n=76)	IE (n=22)	MAE (n=109)	MULTI (n=26)	OTHER (n=86)
Project Supplies	97	32	48	78	64	91	88	78
Hardware	88	39	32	89	32	87	88	72
Software	59	74	63	83	45	65	69	67
Faculty Time	38	77	54	36	59	39	50	50
Travel	32	32	44	22	64	56	77	50
Course Supplies	38	19	32	18	36	26	38	30
Institutional Overhead	21	26	18	12	9	28	19	17
Development Support	12	10	7	14	5	22	31	9
External Consultants	9	6	21	3	5	9	19	5
Other	6	13	13	5	14	7	15	14

* Greyscale shading increases in 20% increments.

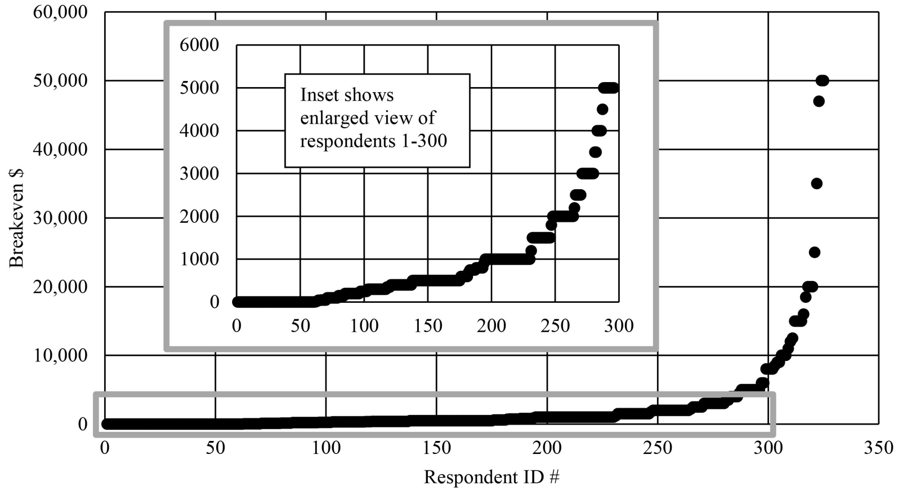


Fig. 21. Average Breakeven Cost per Project (2015 Data).

Table 17. Range of Average Breakeven Cost per Project by Discipline (2015 Data)

	Percent of Respondents*							
Average Breakeven Cost	BME (n=28)	ChE (n=18)	CEE (n=47)	EECS (n=60)	IE (n=13)	MAE (n=83)	MULTI (n=20)	OTHER (n=56)
$0	7	39	47	12	38	7	15	11
$1-500	71	33	23	63	23	24	20	27
$501-1000	11	6	11	20	8	25	0	21
$1001-2000	7	17	6	2	15	12	20	16
$2001-3000	4	0	0	2	0	7	10	11
$3001-5000	0	0	9	2	8	8	5	4
$5001-10,000	0	0	2	0	0	6	15	5
>$10,000	0	6	2	0	8	10	15	5

* Greyscale shading increases in 15% increments.

respondents were asked to provide the minimum, average, and maximum breakeven cost per project (though the survey did not formally define "break-even cost", so respondents may have interpreted it differently). Fig. 21 shows the average values for the 325 respondents from 2015 who provided such data, with each point representing one respondent. The maximum reported breakeven cost was $50,000, but the vast majority of respondents had values much lower. In fact, 300 of the 325 respondents had breakeven costs less than $5000, 200 were less than $1000, and 50 had no costs at all.

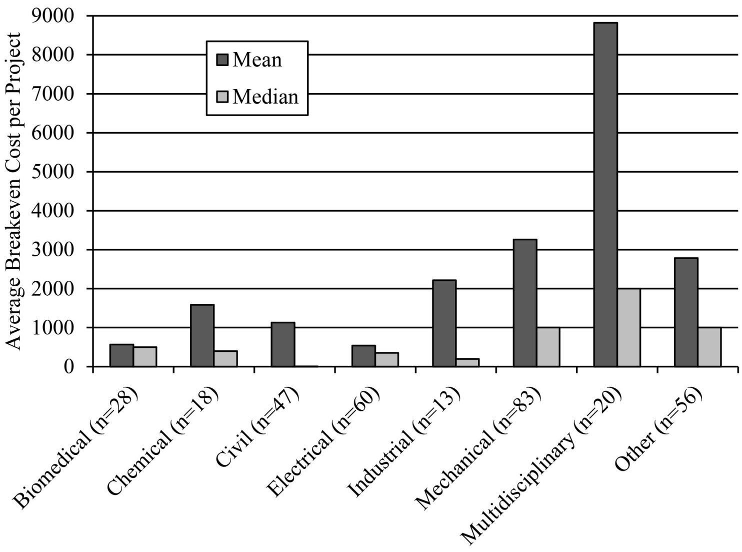


Fig. 22. Mean and Median of Average Breakeven Cost per Project by Discipline (2015 Data).

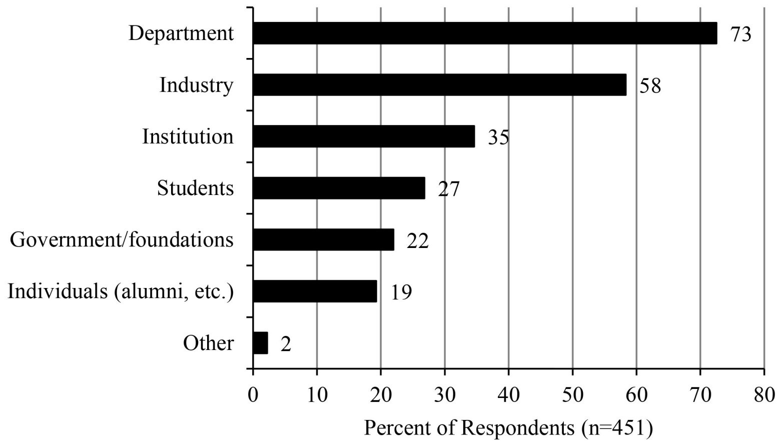


Fig. 23. Funding Sources (2015 Data).

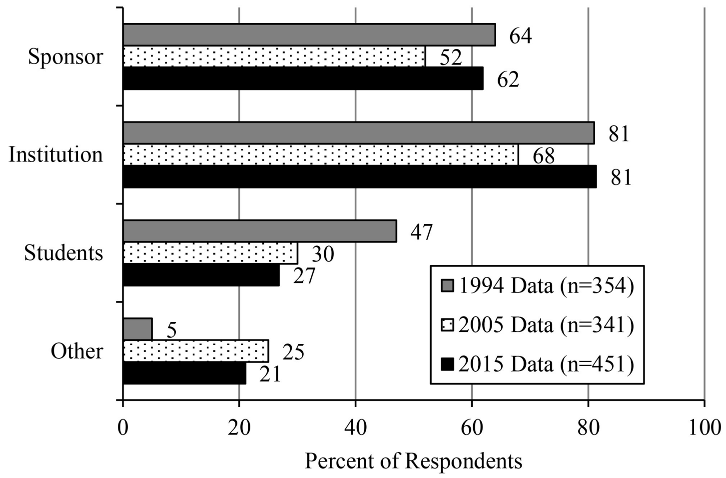


Fig. 24. Funding Sources (Longitudinal Data).

Table 17 shows the breakeven cost data grouped into cost ranges and sorted by discipline and Fig. 22 shows the mean and median value of the average breakeven cost data for each discipline. As is clear from both Table 17 and Fig. 22, the lowest average breakeven costs per project were electrical/computer and biomedical capstone programs. Multidisciplinary capstone programs reported the largest mean and median values of average breakeven cost within their populations, but also had the widest data spread.

Sources of funding for these expenses included a wide range of options, as shown in Fig. 23. Note that the values sum to far more than 100%, indicating that many respondents selected more than one option. Department and industry were sources for more than half of the respondents. The few "Other" responses from 2015 included approaches such as crowdfunding or self-funding by the capstone instructor.

Figure 24 shows the 2015 funding source data compared with the 2005 and 1994 data. (So as to match the broader categories from the earlier surveys, "Department" and "Institution" were combined to be "Institution", "Industry" and "Government/foundations" were combined to be "Sponsor", and "Individuals" and "Other" were combined to be "Other".) Institutions and sponsors have remained the most common funding sources in the past 20 years. Students were less likely to fund their own project in 2015 than they were previously, and individuals such as alumni were nearly as likely to fund capstone projects in 2015 as were current students.

Figure 25 shows the form that the funding takes, as noted by respondents to both the 2015 and 2005 surveys. In both data sets, funding in the form of gifts was the most common. In 2015, reimbursement for expenses was nearly as common as gifts. The "Other" responses in 2015 included such funding forms as contracts, fees, and in-kind donations. That the sum of the 2015 data exceeds the sum of the 2005 data suggests that funding in 2015 came in multiple forms for more capstone programs than it had done previously.

Respondents with external sponsors were asked

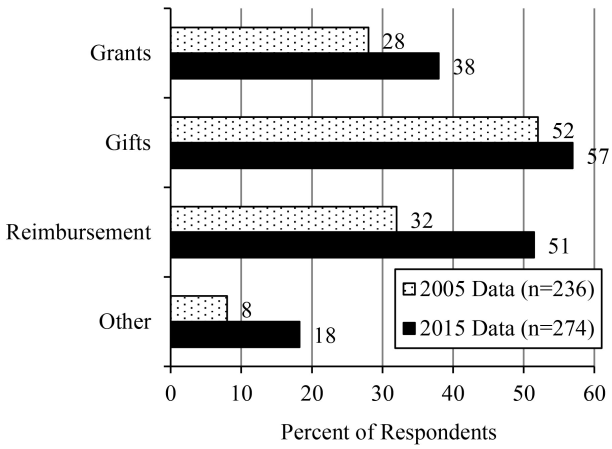


Fig. 25. Forms of Funding (Longitudinal Data).

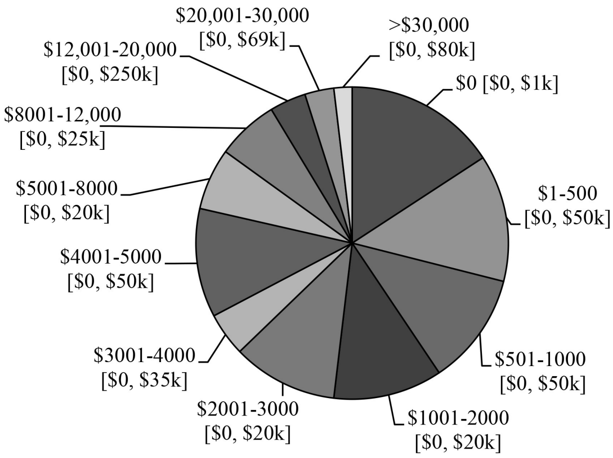


Fig. 26. Average Financial Support Provided by External Sponsors (2015 Data, n = 266, with [min, max] for respondents in given support range).

to provide the average, minimum, and maximum amount of financial support that the external sponsors provided. Fig. 26 shows the average level of support for different dollar ranges, with the lowest minimum and largest maximum for each range shown in brackets. For just over half of the respondents, external sponsors provided an average of $2000 or less per project, whereas for just 5% of respondents, external sponsors provided average funding exceeding $20,000 per project. The minimum level of external funding was $0 for all funding ranges, suggesting that even programs with sizable average funding levels had some projects without any funding from external sponsors. The maximum external funding level was $250,000 for one particular capstone program, but the median maximum was only $5,000, indicating that the largest maximum was quite an outlier.

Figure 27 compares the average external funding levels from the 2015 survey with those from the 2005 and 1994 surveys, not adjusted for inflation or cost of living. (In 1994 and 2005, respondents were asked to choose between the funding categories noted on the graph, whereas in 2015 they were asked to write in a specific number. The data from 2015 were subsequently sorted by categories: $0, $1–500, $501–1000, $1001–5000, and >$5000. "Variable" was an option on only the 2005 survey.) Although 2015 reflected an increase in projects without external funding, overall the average funding level in 2015 was higher than it had been in either previous survey.

Table 18 shows the extent to which the 2015 external funding data vary by discipline. Quite strikingly, more than half of chemical engineering capstone programs averaged zero external funding for their projects, though a handful averaged more than $20,000. One ChE respondent noted "*[Funds are] not an issue. Chemical engineering capstone design process is entirely virtual.*" On the other hand, nearly a quarter of multidisciplinary capstone programs averaged funding greater than $20,000 and more than half averaged funding of >$5,000.

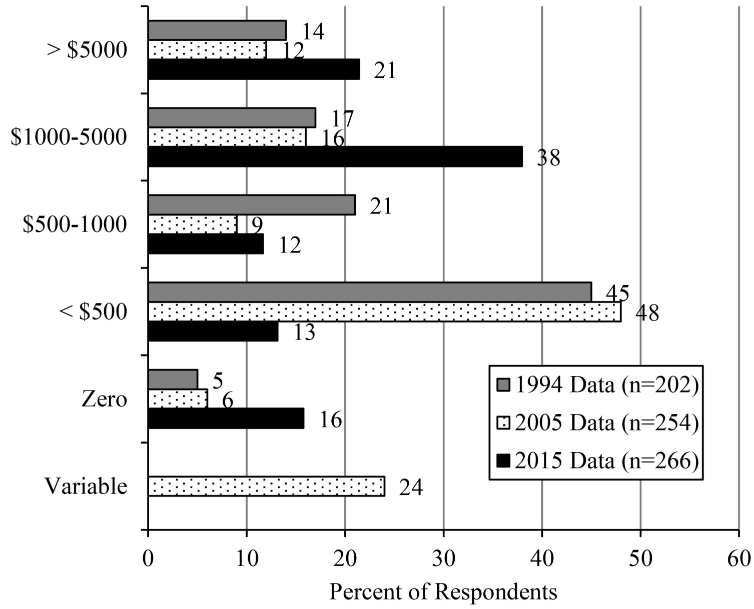


Fig. 27. Average Financial Support Provided by External Sponsors (Longitudinal Data).

Table 18. Average Funding from External Sponsors by Discipline (2015 Data)

	Percent of Respondents*							
Average External Funding Level	BME (n=20)	ChE (n=11)	CEE (n=17)	EECS (n=49)	IE (n=12)	MAE (n=74)	MULTI (n=25)	OTHER (n=58)
$0	20	55	29	20	25	3	8	17
$1-500	40	27	24	16	0	7	4	10
$501-1000	10	0	18	24	0	12	0	9
$1001-2000	10	0	0	6	17	11	12	21
$2001-3000	0	0	0	4	17	19	12	14
$3001-5000	10	9	12	20	17	23	12	9
$5001-10,000	5	0	6	8	17	14	12	14
$10,001-15,000	0	0	6	0	8	3	12	3
$15,001-20,000	5	0	0	0	0	5	4	0
>$20,000	0	9	6	0	0	4	24	3

* Greyscale shading increases in 12% increments.

3.7 Sponsors

Seventy percent of 461 respondents to the 2015 survey noted that they had external sponsors for their capstone design projects. Fig. 28 shows the location of these project sponsors, with the dot size proportional to the percent of respondents for each category. The percent of local sponsors (<20 miles away) has decreased over time, as institutions have begun to look farther away for projects—including out of the country. The option for international sponsors was added in the 2015 survey, and was selected by 13% of respondents.

Table 19 shows the 2015 sponsor location data sorted by discipline. Sponsors within 20 miles were the most popular choice for most disciplines, except for chemical engineering respondents, but more regional sponsors (20-100 miles away) were also common. (Depending on institutional location, of course, sponsors more than 20 miles away may still be considered "local".) All disciplinary groupings had at least some project sponsors more than 100 miles away. The sizable percent of international projects in civil/environmental (25%) and multidisciplinary engineering (23%) respondents is also notable.

Figure 29 shows frequency of student contact with their project sponsors. The data have remained relatively similar over time, with weekly contact with sponsors as most common response. The option of biweekly meetings was added in 2015, and made up 19% of responses. Based on the 2015 data, however, the percent of respondents meeting with sponsors strictly at the beginning and end of the project has fallen dramatically. The percentage of respondents marking "Other" increased in 2015, with respondents noting that contact varies depending on project, sponsor, and team.

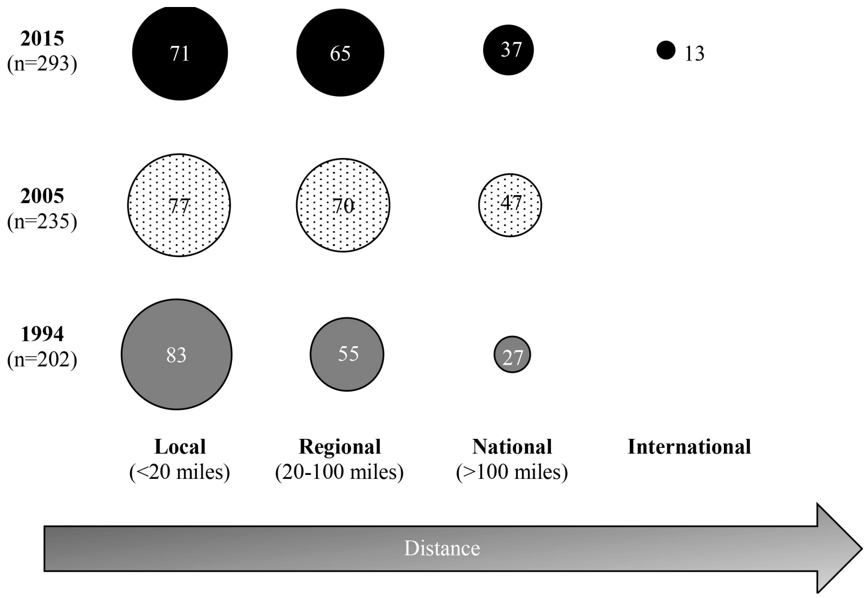


Fig. 28. Sponsor Location (Longitudinal Data, Percent of Respondents).

Table 19. Location of Sponsors by Discipline (2015 Data)

	Percent of Respondents*							
Sponsor Location	BME (n=24)	ChE (n=10)	CEE (n=20)	EECS (n=51)	IE (n=14)	MAE (n=86)	MULTI (n=26)	OTHER (n=62)
Local (< 20 miles)	88	50	75	73	64	67	81	66
Regional (20-100 miles)	50	80	50	61	64	69	77	65
National (> 100 miles)	25	40	35	24	29	42	58	44
International	8	10	25	6	7	13	23	15

* Greyscale shading increases in 20% increments.

Some amount of repeat sponsorship was common for at least some, if not all, respondents in 2015, as seen in Figure 30. Comments from respondents noted variability depending on year and sponsor. For example, some sponsors "*take time off*" and then return in future years.

Figure 31 shows the data for intellectual property (IP) ownership from capstone projects across all three surveys (note, "Other" was an option only in 1994). The prevalence of IP ownership in general has increased over time and sponsors continue to be the most common owners of project IP. Based on additional 2015 data, however, the ownership was usually divided between more than one entity.

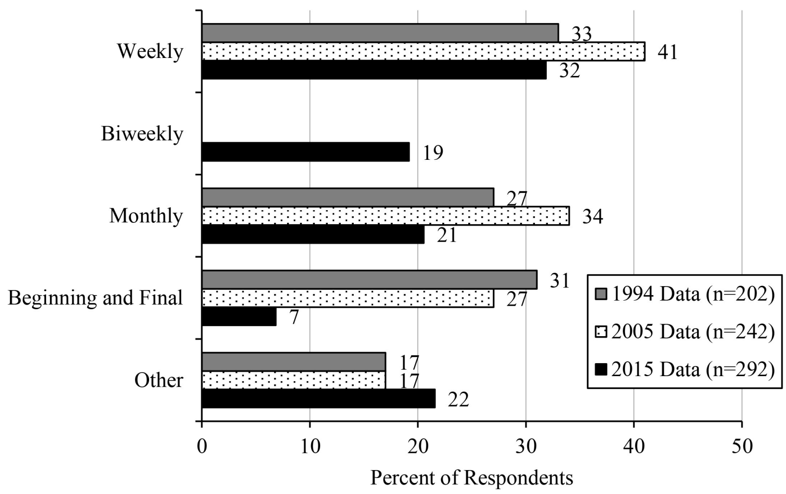


Fig. 29. Frequency of Student Contact with Sponsors (Longitudinal Data).

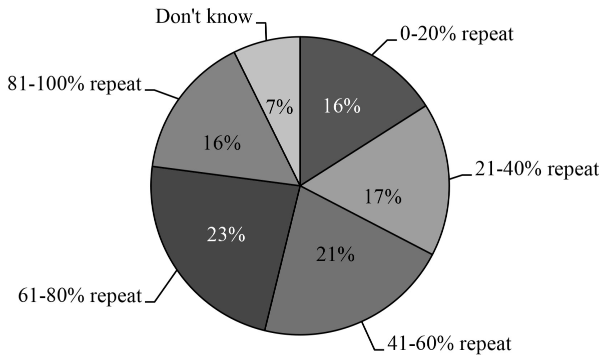


Fig. 30. Percent of Repeat Sponsors (2015 Data, n = 208).

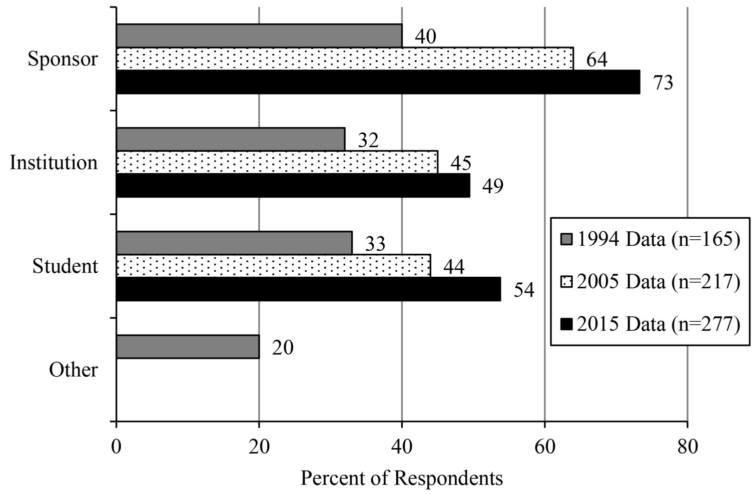


Fig. 31. Intellectual Property Ownership (Longitudinal Data).

Nearly half (70 of n = 145) of 2015 respondents who provided write-in responses regarding dividing IP ownership commented that division varied by project and/or was subject to negotiation or sponsorship agreements. Alternatively, students were sometimes given royalties in place of IP ownership.

The IP ownership data from 2015 are shown across disciplines in Table 20. Similar to the overall data, the sponsor was the most common IP owner for nearly all disciplines. Exceptions included civil/environmental engineering, who nearly always gave ownership to the institution, and electrical/computer engineering, which listed students as IP owners most often, likely as a result of the popularity of entrepreneurial projects in EE/CS (see Table 11).

3.8 Experience and opinion

Toward the end of the survey, respondents were asked about their personal experience and opinions. Fig. 32 shows the type of faculty position held by the survey respondents. More than 50% of respondents held tenured positions at their institution, whereas nearly a quarter were non-tenure-track, but permanent. The "Other" responses included adjunct position, emeriti, and combinations of multiple options..

Respondents were also asked how many years of experience they had in professional work outside of academia (e.g. industry, government) in any field of engineering. As shown in Fig. 33, capstone design instructors brought substantial experience from

Table 20. Intellectual Property Ownership by Discipline (2015 Data)

	Percent*							
IP Owner	BME (n=24)	ChE (n=10)	CEE (n=10)	EECS (n=53)	IE (n=14)	MAE (n=81)	MULTI (n=26)	OTHER (n=59)
Sponsor	88	70	60	60	86	75	88	69
Institution	67	40	90	49	43	41	27	61
Students(s)	71	40	40	72	50	56	42	39

* Greyscale shading increases in 20% increments.

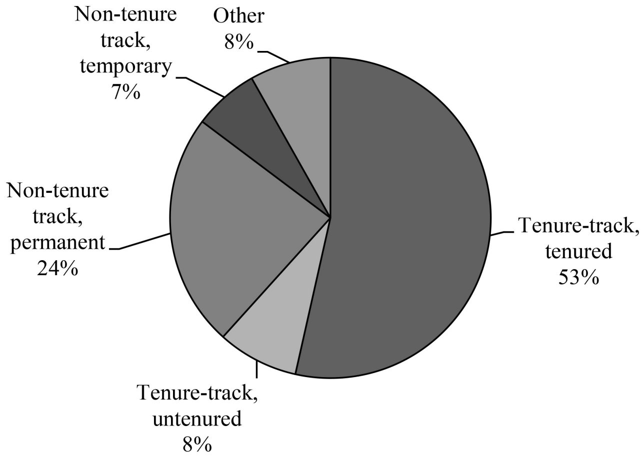


Fig. 32. Faculty Position Type Held by Respondents (2015 Data, n = 441)

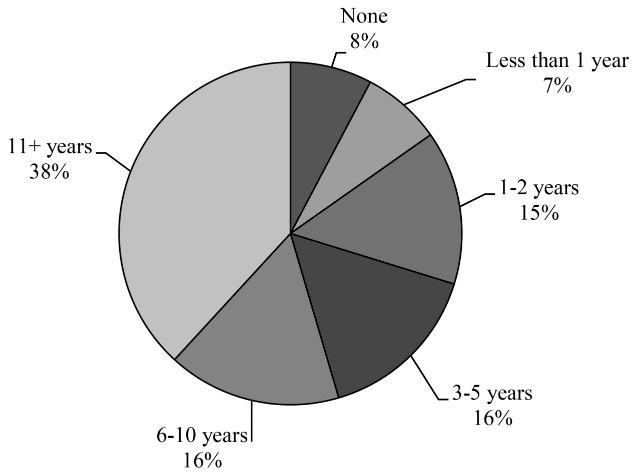


Fig. 33. Years of Experience in Engineering Professional Work outside of Academia (n = 440).

engineering industry and government work to their teaching. More than half of respondents had at least 6 years of work experience outside academia, whereas only 15% had none or less than one year. Clarifying comments provided by some respondents suggested that the length of professional work experience far exceeded 11 years; respondents included multiple write-ins for 25 and 30 years of experience. As one respondent noted, "*You need more choices. I have 40 years.*" Moreover, 85% of 410 respondents noted that their professional work outside of academic included design, further strengthening their preparation to teach capstone design.

One of the open-ended questions on the survey asked respondents "What do you enjoy most about being involved with capstone design?" Responses clustered into eleven categories as shown in Table 21. Nearly a third of the responses addressed some aspect of personal success. Of those, the most common responses were related to student success and accomplishment (n = 34), student growth and confidence (n = 33), and application of student learning (n = 26). Sample responses included "*Seeing the students tackle projects that initially seem much too large for them, and having them make substantial progress*", "*Seeing students mature in confidence*", and "*Seeing the students apply the things they've learned throughout their time at the university*". Another large category of responses related to interactions of various sorts, particularly interactions with students (n = 75) and interactions with industry (n = 25): "*I find the interactions with the students to be very rewarding*" and "*I enjoy the variety of the projects and the organizations that I work with. It interests me to be aware of the issues/problems our sponsors face.*"

Responses to the question "What are your biggest challenges regarding capstone design?" grouped into fourteen categories as shown in Table 22. Nearly one third of the respondents addressed challenges relating to some aspect of workload and time, with comments such as "*The short amount of time involved and the time it takes to*

Table 21. Categories and Content Themes Regarding Enjoyment from Capstone Design (2015 Data)

Category	Percent of Respondents* (n=361)	Content Themes (in descending order of frequency)
Personal Success	32	student success and accomplishment; student growth and confidence; application of previous learning and skills; student joy and excitement; student pride and self-recognition of achievements; "aha" moments; student presentations; learning from failures; student risk-taking
Interaction	30	working with students; interacting with industry clients and sponsors; faculty learning from students; collaborating with other faculty/departments/schools; interacting with community
Professional Development	17	transformation from students to professionals; student motivation and ownership; professional development and applications; teamwork experiences; broad topics beyond just technical skills
Variety	14	variety and variability of projects; new ideas and perspectives; variety of topics and skills
Process	13	design process; progression of projects; open-ended problem solving; building and testing prototypes, hands-on experience
Advising	13	advising/coaching/mentoring/guiding students; sharing personal experiences and expertise; student/teacher relationship
Real World	12	applied and relevant projects and problems; societal impact and value of projects; staying current with new techniques and technologies; connection between academia (theory) and industry (practice)
Creativity	10	creativity/brainstorming/innovation; interesting problems
Project Success	8	overcoming tough and complex problems; providing good final result; sponsor satisfaction
Uniqueness	3	not a standard course; designing the overall experience; proposing and selecting projects; being part of tradition
Extreme	1	all of it; do not enjoy

* Greyscale shading increases in 7% increments.

complete a project" and "*400+ students, 70–80 projects annually, 20 Faculty advisors, coordinated by 1 person.*" Another large category of responses were project-related, most prominently expressing challenges related to finding appropriate projects for the given time frame (n = 44) and financial support (n = 36): "*Finding projects that are appropriately challenging from sponsors that are willing to contribute financially*". Multiple responses addressed the category of student involvement, such as getting and maintaining student commitment (n = 26), and helping students start and manage projects (n = 20): "*Keeping the students moving forward. They seem to be getting busier and busier with other classes as the years go by.*"

4. Discussion and future work

As a successor to both the 1994 and 2005 surveys of capstone design courses [1, 2], the 2015 survey reprised the questions of its predecessors in addition to some new questions informed by other surveys and discussions within the capstone design community. The data were grouped in eight main categories: respondent profile, course logistics, pedagogy, faculty and students, projects and teams, expenses and funding, sponsors, and experience and opinion. The key themes from the 2015 data plus relevant longitudinal and disciplinary comparisons are summarized below, followed by discussion of their significance and plans for future work.

- Respondent Profile: The 2015 survey respondents represented capstone programs across a wide range of engineering disciplines. As was also true in the previous surveys, mechanical/aerospace disciplines had the largest set of respondents, followed by electrical/computer, and civil/environmental. The 2015 survey respondents also represented biomedical engineering and multidisciplinary capstone programs as well. The 2015 data reveal a broad range of capstone program age, spanning from programs that had just started to others more than 50 years old. Biomedical and multidisciplinary capstone programs were relatively newer, whereas chemical engineering capstone programs were relatively older.
- Course Logistics: Capstone design courses can be structured multiple ways, but the most common approach in 2015 as in previous years was to run the design projects and the class in parallel. The duration of capstone design courses has

Table 22. Categories and Content Themes Regarding Challenges in Capstone Design (2015 Data)

Challenges	Percent of Respondents (n=364)	Content Themes
Workload/ Time	30	time in general; increasing class size; instructor time needed; other student commitments; workload; time spent reading, writing, editing; prototype fabrication and testing
Project-related	25	finding appropriate projects for the given time frame; financial support; finding enough projects for the given time frame; equity across projects and faculty; service learning projects; getting internal project data
Student Involvement	23	getting and maintaining student commitment; helping students start and manage projects; student discomfort with open-ended problems; unmotivated students; encouraging student independence and ownership; getting students outside their comfort zone; students going beyond the project scope; getting students to justify and quantify design decisions
No Support	12	missing institutional support in value of capstone design courses; equipment and facilities; having to "sell" the importance of the course; need staff and admin support; institutional red tape
Student Teams	12	keeping healthy team dynamics and student teamwork; underperforming students and teams; uneven effort within teams; assigning and balancing teams; value of non-technical skills are just as important as the engineering; perception of design as "soft engineering"
Faculty Involvement	7	faculty engagement; faculty without industrial experience; keeping faculty from doing the project themselves; staying in the loop without being nosy
Student Preparation	6	understanding wide range of student preparation; student skills lack range of experience; encouraging application of previous knowledge and skills; student confidence
Industry Involvement	6	finding industry mentors or sponsors; personnel and organizational changes and challenges in industry; sponsor distance
Meeting Expectations	5	ensuring high quality deliverable and student success; balancing expectations; ensuring all team members learn as much as their potential allows, educational benefit for all; ensuring students are ready for industry; accomplishment with high stakes
Evaluation	5	evaluation (time and/or process); teaching evaluations; ABET assessment and requirements
Variety/ Breadth	5	mentoring many different disciplines; need for diverse set of projects given student interests; keeping current in the field(s); variety from year to year; translating design terminology and language across disciplines; incorporating entrepreneurship;
Course Logistics	4	overall coordination with other departments, schools, institutions; continuous improvement
Real World	2	distinguishing between real world and theoretical applications; real world obstacles that limit depth of work; leaving the classroom structure and not letting it limit their design potential
Misc.	2	no challenges; design work with students; export control

* Greyscale shading increases in 6% increments

increased; more than half of the 2015 survey respondents reported having a two-semester Capstone course, and some had even longer durations. Just over half of 2015 survey respondents included faculty and/or students from at least two different disciplines in their capstone courses. Capstone design commonly included design prerequisites; only 20% of 2015 survey respondents noted they had no such prerequisites.

- Pedagogy: Capstone design courses typically covered a wide range of topics, often geared toward professional preparation. The top five topics selected by respondents to the 2015 survey were written communication, planning/scheduling, oral communication, concept generation/selection, and team building/teamwork. Regarding the "product vs. process" debate, 2015 survey respondents tended toward a balanced approach or a slight emphasis on process, with more emphasis on process for particular disciplines. For evaluation of student work, capstone design instructors themselves provided the most input, followed by project coaches and industry liaisons. Final reports, presentation, and product had the largest role in evaluation, but process and design reviews were also important.
- Faculty and Students: Capstone design was considered normal teaching activity for tenure and promotion by nearly all respondents to the 2015 survey, but typically very few faculty members

(just one or two for more than half of the respondents) received teaching credit for their involvement in capstone design; fewer than 10% of respondents provide capstone-related teaching credit to all of their departmental faculty. Moreover, student numbers in capstone design have increased in the past decade; the average capstone enrollment in 2015 was 51, with some respondents noting upwards of 200 students per capstone course cycle. While student/faculty ratios of 20:1 or less were most common, some programs had ratios exceeding 60. Expectations of student hours spent have increased as well; the median time bracket in 2015 was 7-9 hours per week, up from 4–6 hours per week in 2005. The majority of 2015 respondents employed a hybrid model where some/all class time was provided for capstone work but students were responsible for finding other times outside of class. Many faculty expressed concern about increasing work load and time commitment; the capstone community should take note of this concern in their efforts to promote a quality capstone experience for both students and faculty.

- Projects and Teams: Capstone design projects were sourced from many places, most commonly industry, followed by faculty research. The prevalence of entrepreneurial and service learning projects has increased since 2005. Over half of 2015 survey respondents utilized external contacts as a means of finding projects, and also recognized the importance of "good fit" when selecting and vetting possible projects. In keeping with rising enrollments, the number of projects per course cycle has increased in the past ten years; 25% of respondents in 2015 had more than 15 projects concurrently. Team sizes of three or four students were most common. Half of the multidisciplinary respondents, however, had more than 15 projects per course. Student choice was the most common way to assign students to teams.
- Expenses and Funding: Typical expenses in capstone design courses included project supplies, hardware, and software, among others. While the range of expenses varied significantly by institution, discipline, and especially project, many capstone design courses had breakeven costs less than \$1000. The institution and external sponsors were the primary source for project funding; in 2015 students were less likely to fund capstone design projects than they had been in the past. Sponsor funding ranged from \$0 to a reported high of \$250k, but 75% of programs that responded in 2015 received less than \$5000 per project from sponsors, and 50% received less than \$2000 per project, typically in the form of gifts, grants, or reimbursement for expenses.
- Sponsors: The majority of sponsors were still located within 100 miles of the institution and many within 20 miles; 13% of 2015 respondents also collaborated with international sponsors. At least some amount of repeat sponsorship was common for 2015 respondents. The level of ownership of intellectual property from capstone design projects has increased over the past 20 years; external sponsors remained the most likely owner, but ownership was often divided and/or negotiated.
- Experience and Opinion: Capstone design faculty commonly had previous industrial experience involving engineering design; more than half of the 2015 respondents indicated six or more years working in industry, and many respondents had worked for 25 or more years. More than half of 2015 survey respondents held tenured positions at their institution, whereas nearly a quarter were non-tenure-track, but permanent. The most commonly reported reasons that respondents enjoyed capstone design were related to personal success or interaction opportunities. On the flip side, the 2015 respondents had multiple challenges with capstone design, especially related to heavy workload, limited time, and project numbers/funding.

Collectively, the 2015 survey results serve as (1) a compilation of logistical and implementation information about recent engineering capstone education programs and (2) a springboard for future research on the subject to enrich and advance capstone education in engineering. Although these data do not necessarily represent best practices for they are not tied to programmatic outcomes or student achievement, nor, as other researchers have reported [18], do they represent practices at solely top-ranked institutions (a potential proxy for best practices), the highlights do represent themes from current practices at hundreds of capstone programs over 20 years. Given the emphasis on continuous improvement in engineering education as part of ABET accreditation [19], one could infer that capstone practices that are common across programs and/or over time are effective practices, and, as such, are valuable for capstone design instructors and administrators to consider and even adopt.

The decennial capstone survey initiative is motivated by a desire to better understand and improve engineering capstone courses and practices employed by capstone educators on a national and, ultimately, global scale. The 2015 survey has already been distributed to capstone programs in Australia and New Zealand; it would be interesting to extend this survey to additional countries or world regions as well. The surveys to date have been distributed to and primarily completed by capstone faculty; another logical extension of this survey initiative, especially with an eye toward identifying best practices, is to include input from students/recent alumni and employers. Capstone design educators interested in partnering in such research are encouraged to contact the authors.

Future survey design would also benefit from some of the lessons learned from implementing the 2015 survey and its predecessors, both in content and in format. For example, accurately capturing capstone program financial information and extent of faculty involvement (hours, FTE, etc.) is challenging. Likewise, documenting age of capstone design courses is complicated because courses change both slightly and substantially over time. Regarding topics within capstone design, querying how topics are covered, not just what topics are covered, is useful. Capturing expected student time spent is possible, but actual time spent is harder to report. The 2015 survey was quite long (requiring on the order of 30-45 minutes to complete), but there is a trade-off between having a comprehensive data set every 10 years and conducting a number of smaller surveys annually or bi-annually; given survey fatigue, longer surveys less often may be preferable. Including more fill-in-the blank questions requires more data processing but allows respondents greater flexibility in their responses. Likewise, including open-ended questions enables rich, in-depth responses. Finally, including mechanisms for triangulating responses to confirm accuracy/validity where possible is useful.

5. Conclusions

The 2015 Capstone Design Survey continued the decennial documentation of the variety of implementation strategies for engineering capstone design programs across the United States. The survey included quantitative, categorical, and open-ended questions about course logistics, pedagogy, faculty and students, projects and teams, expenses and funding, sponsors, and experiences and opinion. The 522 respondents to the 2015 survey represented 464 distinct departments and 256 institutions across a great variety of engineering disciplines. Courses were largely structured with design projects and class run in parallel over two-semesters, and typically covered a wide range of topics often geared toward professional preparation. Student numbers in capstone design have increased in the past decade, along with number of projects per course cycle. Capstone design projects were sourced from many places, most commonly industry, followed by faculty research. While the range of expenses varied significantly by institution, discipline, and especially project, many respondents listed institution and external sponsors as the primary source for project funding. Qualitative responses reported that personal success and interaction opportunities were the most enjoyable aspects of capstone design, while many respondents struggled with heavy workload, limited time, and project numbers/funding. The data gathered from this 2015 survey and its predecessors are an important step in understanding, assessing, and ultimately improving engineering capstone design education.

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