2006-1781: 2005 NATIONAL SURVEY OF ENGINEERING CAPSTONE DESIGN COURSES

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2005 National Survey of Engineering Capstone Design Courses

Abstract

This work details a survey of engineering capstone design courses nationwide conducted in 2005. The survey is a follow-up to one conducted in 1994 by Todd et al.[1], reprising the questions of its predecessor plus requesting additional information. The 2005 survey was implemented online, with requests sent via email to representatives of all ABET-accredited engineering programs (1724 programs at 350 institutions, as of 2004). The online survey yielded a strong response, with 444 programs from 232 institutions submitting responses. This corresponds to a 26% response rate from engineering programs and a 66% response rate from institutions. The results of this survey, with a focus on developments in the past ten years, are presented graphically and discussed. Particular focus areas include course logistics, faculty involvement, project coordination, funding details, and industry sponsorship. The results serve as a snapshot of current practices in engineering capstone design education as well as an indication of trends over the past decade.

1. Introduction

Capstone design courses offer engineering students a culminating design experience on an applied engineering project. With a longstanding history reinforced by support from the Accreditation Board for Engineering and Technology (ABET), these courses have become common in engineering departments across the United States. The composition of capstone courses, however, varies widely. In 1994, Todd et al.[1] conducted a survey of engineering departments throughout North America to capture educational and logistical practices in capstone design courses at the time. Their results[2,3] provided a wealth of information about their respondents' capstone courses plus comments about plans for future modifications.

Since then, a number of other surveys regarding one or more aspects of capstone design have been conducted, though none were intentional successors to the 1994 survey. Indeed, the intervening surveys have focused on specific areas such as assessment in capstone courses[4], or been limited to particular disciplines[5]. This 2005 follow-up survey was motivated by a desire to understand true current practices and identify what, if anything, has changed in the past ten years. Additionally, we hoped to use the results to inform the capstone course at our own institution plus share the data with others so they could do likewise.

2. Survey Methods and Respondents

The purpose of the survey was not only to discern trends developing since 1994, but also to acquire a general picture of the state of capstone engineering today. To this end, we developed a draft survey in the fall of 2004 that combined most of the questions from its 1994 predecessor[1], with some new questions regarding course participant feedback, faculty obligations, and project funding. We sent the draft to several colleagues in capstone education for feedback and incorporated many of their suggestions for additional or reworded questions.

The final version was posted as an online survey with 7 sections and a total of 57 questions. To identify respondents, an initial page asked for a name, department, institution and the presence of a capstone program before granting access to the survey. Questions focused on course details, faculty involvement, project information, feedback from course participants, project funding, and industry sponsorship. A page was devoted to any further comments respondents wished to make, with several open-ended questions as suggestions. In May 2005, we sent an email to the department chair of each accredited undergraduate engineering program in the United States, asking that it be forwarded to the person in charge of each capstone course. If the program had no capstone courses, the department head was asked to indicate this on the initial page, and submit that page. Names and contact information for these programs had been compiled earlier using ABET's online listing of accredited engineering programs as of 2004[6]. We sent a follow-up email in June to all those who had not yet responded, then another in October to a targeted group of still non-responding institutions: ranking schools from *U.S. News and World Report*[7,8]. Responses were accepted until early November 2005.

Of the 1724 programs at 350 institutions surveyed, 444 programs from 232 institutions replied, yielding response rates of 26% among programs and 66% among schools. As discussed by Todd et al.[3], whose survey yielded a 35% program response rate, varied reasons exist for the low percentages of responding institutions, including "faculty workload, timing of the survey" and perhaps particularly in 2005, the overwhelming volume of email in which the survey could have been missed or dismissed.

Survey responses were compiled and processed electronically. Most of the questions had participants choose from a list of responses, and could thus be digitally tallied and graphed with relative ease. The qualitative section at the end presented more of a challenge, however, and the data from that are still being processed. Many questions throughout the survey allowed space for comments, particularly if "Other" was an option. We read through these comments, and if enough respondents wrote in a similar answer, tallied the remark and presented it with the corresponding quantitative data.

The questions/results presented in this paper are primarily those discussed in Todd et al.'s "A Survey of Capstone Engineering Courses in North America"[3], in keeping with the purpose to follow-up on that work. Where the questions from the two surveys lined up closely, the 1994 and 2005 data are depicted in bar graphs. Pie charts are used where supplementary data were requested on 2005 questions. The graphs are arranged in an order and format similar to both the 1995 paper[3] and the 2005 survey.

3. Survey Results and Discussion

A comparison of results from the 2005 and 1994 capstone surveys is presented below. The data are organized into six main categories: Respondent Profile, Course Information, Faculty Involvement, Project Information, Funding Information, and Industry Sponsorship. Within each category, the specific survey results are summarized in graphical format and discussed with accompanying commentary.

3A. Respondent Profile

This section describes the profile of the survey respondents. Figure 1 shows the number of respondents sorted by department. The specific categories were chosen for ease of comparison; departments were grouped as closely as possible. Note, that since many departments represent several related disciplines, the categories represent more than just the listed department. For example, "Chemical" includes pure chemical engineering departments, as well as chemical and biomolecular, chemical and biological, and chemical and biomedical. Pure biomedical engineering departments, on the other hand, were grouped in "Other Engineering". Similarly, some of the "Civil/Environmental" departments include architecture or surveying and some of the "Industrial" departments include manufacturing or systems. The "Other Engineering" category included such departments as biomedical, geological, materials, mining, nuclear, and petroleum engineering as well as general engineering (15% of the "Other Engineering" category). As is clear from Figure 1, the respondent population for both the 1994 and 2005 surveys spanned across the disciplines, with no single discipline overwhelming the others. The substantial increase in "Other Engineering" departments responding to the 2005 survey likely reflects the rise of specialized, interdisciplinary, and general engineering departments in the past decade[9].

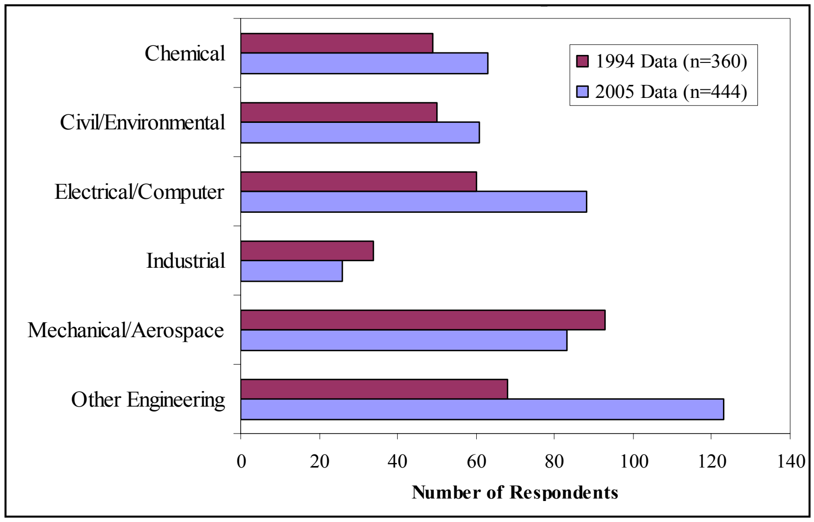


Figure 1: Number of Respondents by Department

Figure 2 depicts the percent overlap between the survey respondents from 1994 and 2005. The overlaps were calculated as a percentage of 1994 responses. The largest overlap is in the chemical engineering departments in which 40% of the survey respondents in 1994 also responded to the 2005 survey. The other overlap percentages range from 21 to 31%, with an overall average of 28%. The non-majority overlap can be attributed to several reasons. First, both the

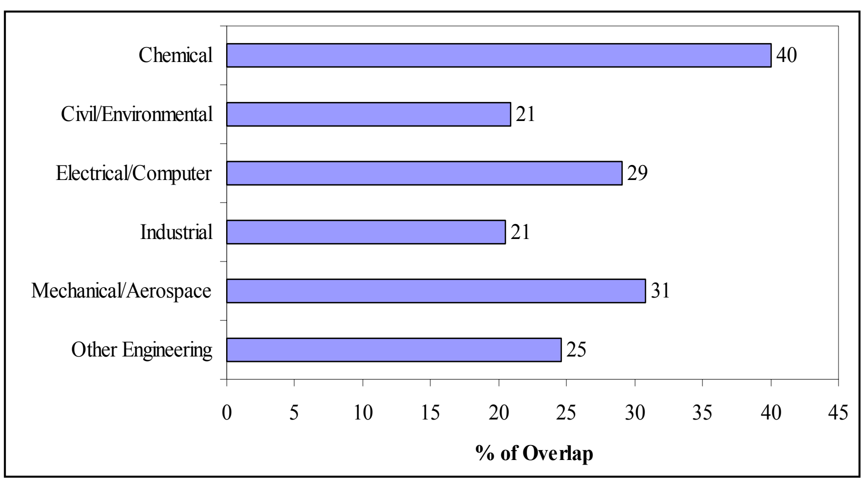


Figure 2: Percent Overlap between 1994 Respondents and 2005 Respondents

1994 and 2005 surveys were sent to large target populations and received response rates less than 35%, hence it is not surprising that the survey responses do not overlap substantially. In addition, the target populations were not identical: the 1994 survey was sent to 1021 engineering departments based on the American Society of Engineering Education (ASEE) 1993 Directory[10], whereas the 2005 survey was sent to 1724 engineering programs based on the ABET Directory as of 2004[6]. Not all ABET-accredited programs are listed in ASEE, nor are all ASEE-listed departments ABET-accredited. Perhaps most importantly, 45% of respondents to the 2005 survey noted that their capstone courses were less than ten years old. Given that the overwhelming majority of respondents to both surveys (96% in 1994 and 98% in 2005) reported offering a capstone course, the fact that so many of the 2005 respondents started capstone courses within the past decade means that they did not participate in the 1994 survey, thus further explaining the lack of overlap.

In summary, general trends within the respondent pool suggest that both surveys achieved a fairly even distribution among departments, and specific respondents overlapped by 28% between the two sets of data. The most notable change in distribution was an increase in the "Other Engineering" departments for 2005 respondents. The overlap can be accounted for by considering the separate groups each survey targeted, a response rate for both surveys of less than half the target population, and the emergence of new capstone courses in the past decade. With these and other factors at work, the fact that the responses overlap at all is a testament to engineering faculty nationwide and their willingness to contribute to such surveys!

3B. Course Information

This section focuses on details of the capstone courses themselves. Data of interest include the type of capstone teams (individual, departmental, or interdisciplinary), course structure and sequence, course duration, types of interdepartmental participants, and topics taught.

Figure 3 shows in which types of capstone design courses the respondents participate. Note that the responses sum to more than 100 percent since respondents could select more than one option. As was true in 1994, the vast majority of departments still organize students around departmental teams. It is interesting to note, however, the decrease in individual teams as well as the increase in interdepartmental teams, suggesting that departments are emphasizing teamwork and increasing opportunities for cross-disciplinary collaboration. Many of the respondents who selected "Other" commented that they had either multiple capstone courses in their department and/or a sequence of design courses that spanned more than a single year.

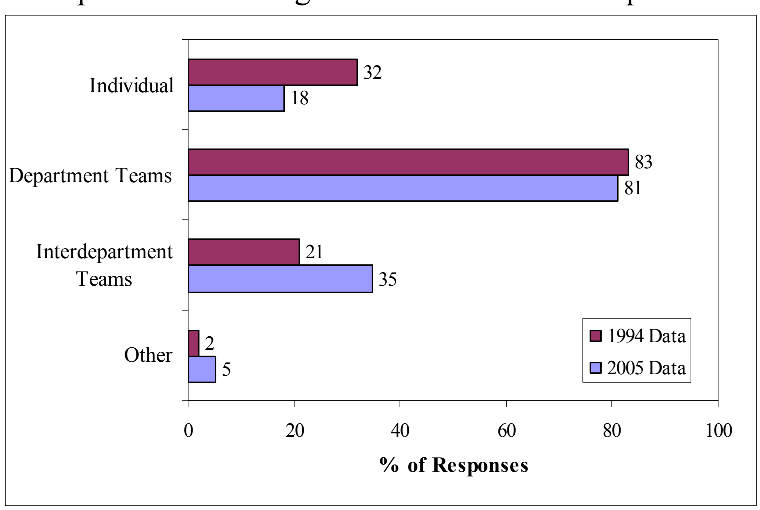


Figure 3: Type of Capstone Design Course

Figure 4 depicts the structure and sequence of the capstone course, with regard to class and project. The majority of respondents in 2005 offer a capstone course in parallel with design project(s), as did the majority in 1994. The change in data, however, suggests an increase in this approach coupled with a decrease in separate "class then project" or "project only" approaches. Capstone courses without a project component are, as before, a very small minority.

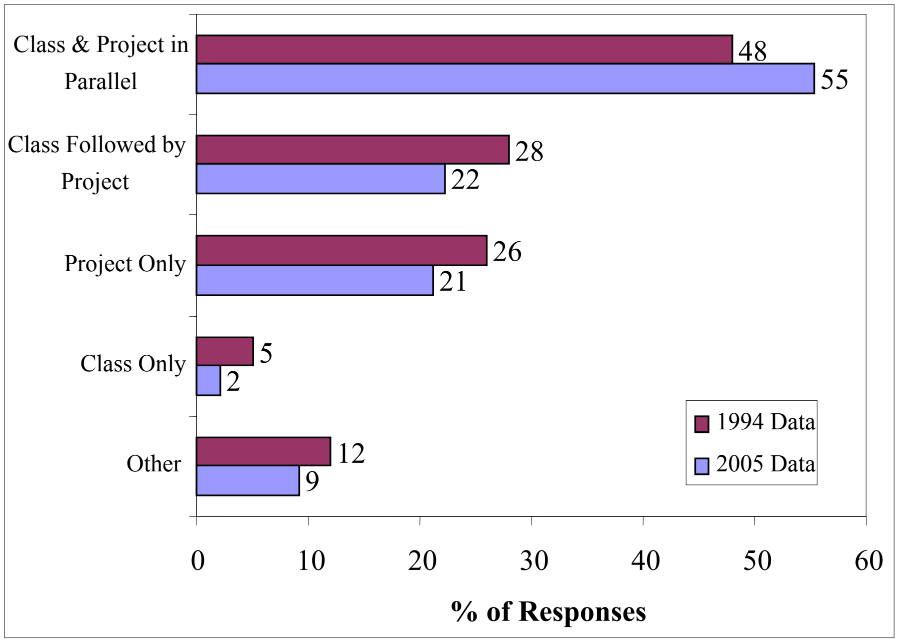


Figure 4: Structure and Sequence of Capstone

Regarding the instructional component, some of the respondents commented that their courses have formal instruction in the first few weeks and more informal meetings thereafter, while others noted having occasional instruction as needed throughout the course. Some respondents specifically mentioned using class time for students to meet with clients/advisors and to present informally to their peers.

Figure 5 provides the data for the duration of both the capstone course and project. The 1994 data are reported with the course and project responses combined, whereas the 2005 data report them separately. Overall, the data do not show a sizable change over the past 10 years; the majority of respondents offer their capstone courses as either a one-semester or two-semester option. Responses from the "Other" category ranged from courses only a few weeks long to those running three or more semesters, and projects that started mid-semester or were combined with other smaller projects.

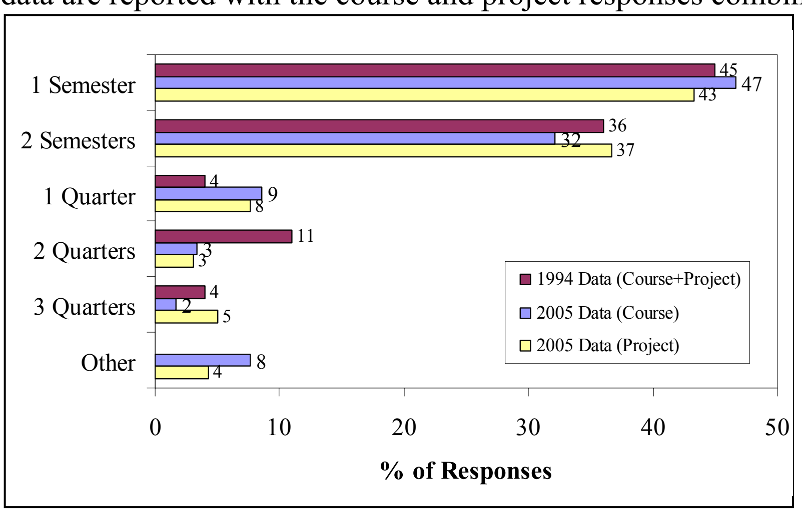
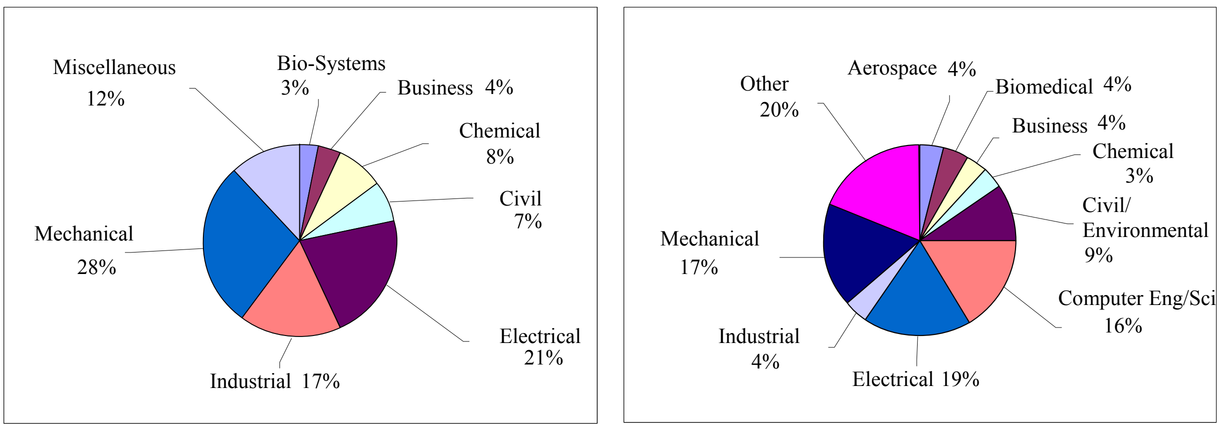


Figure 5: Duration of Capstone Course and Project

Figures 6A and 6B provide additional insight into the interdepartmental teams by illustrating the range of departments participating in interdepartmental and/or interdisciplinary capstone project teams. In keeping with the reported 1994 data, the results are not normalized by number of respondents, but rather by the total number of departments that participate in interdepartmental capstone courses. This total includes the responding departments as well as those departments whose students participate with them (330 in 1994 and 716 in 2005).

The increase in total departments participating in interdepartmental capstone projects is paralleled in the increase of types of departments. Indeed, the decrease in percentage of mechanical and industrial (28% to 17%, and 17% to 4%, respectively) is compensated by the increased percentage of aerospace and computer engineering/science in 2005, plus the increase of the "Other" category, which includes departments ranging from systems engineering to physics to theatre. Of particular note is the surge of computer engineering and computer science collaboration in the past decade, reflecting the growing role of computers in engineering design.



Figures 6A and 6B: Departments Participating in Interdepartmental/Interdisciplinary Capstone Courses (6A = 1994 Data, 6B = 2005 Data)

On one question in the 2005 survey, respondents were asked to select from a list of 23 different topics (plus a "write-in" option) what they included in their classes. Figure 7 shows the results from the 2005 survey compared with the most frequently taught subjects reported from the 1994 survey. Table 1 lists the results for the 2005 survey, sorted by frequency. The topics marked with a (*) were also included in the 1994 survey. Responses for the "Other" write-in option included another 75+ topics, ranging from material selection to poster communication to corporate culture. In both the graph and the table, the results sum to far more than 100%, indicating that most respondents selected multiple options.

As shown in Figure 7, the subjects reported as most frequently taught in 1994 were even more frequently or at least as frequently taught in 2005. (Note, the reported data for "Teamwork Essentials" in 2005 is an average of the two reported categories "Teambuilding" and "Team Dynamics", as listed in Table 1.) In addition, several topics added to the 2005 survey, such as written communication, decision making, and leadership, proved to be widely taught subjects. Finally, it is interesting to note the type of topics reported as most frequently taught in 2005. Professional skills form the majority of the most frequently taught subjects, as shown in the left side of Table 1, whereas technical skills are more prevalent in the remaining topics on the right side of Table 1. As encouraged by ABET's Engineering Criteria[11] and exemplified in many engineering programs[12], professional skills are an important component of engineering education, and the capstone experience is one place in which they are prevalent.

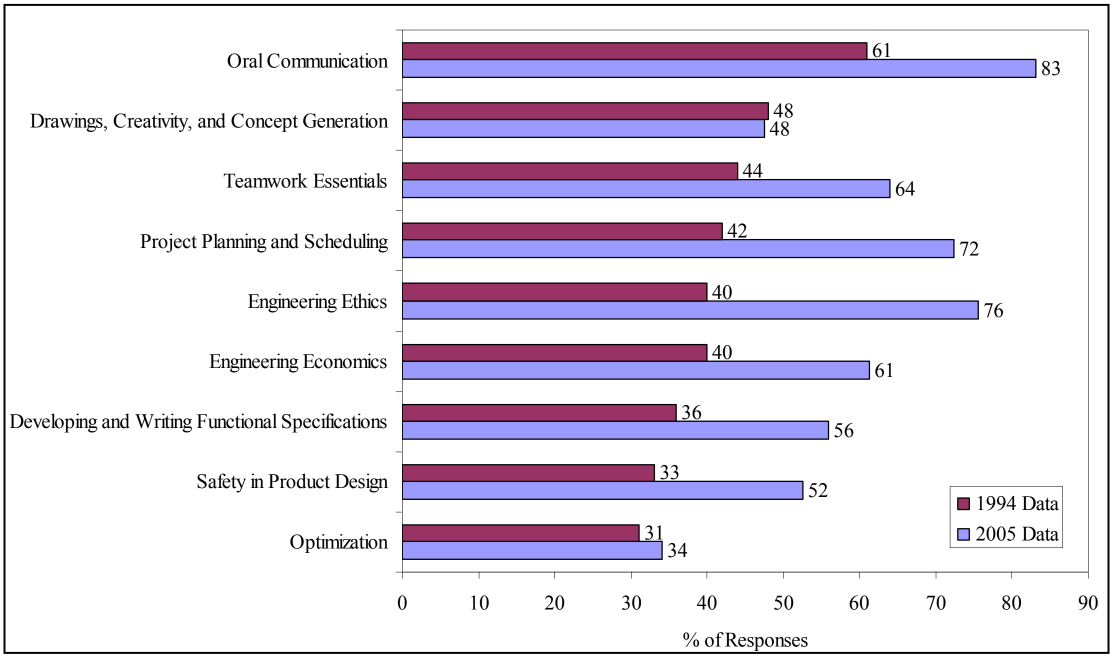


Figure 7: Subjects Taught (Most Frequently for 1994 Survey)

Topic	%	Topic	%
Written Communication	87	Drawings/Creativity/Concept Generation *	48
Oral Communication *	83	Analysis Tools *	46
Engineering Ethics *	76	Intellectual Property/Patents	45
Project Planning and Scheduling *	72	Prototyping and Testing *	37
Decision-Making	68	Optimization *	34
Teambuilding	66	Sustainability	29
Team Dynamics	63	Manufacturing Processes *	29
Engineering Economics *	61	Risk Assessment	29
Developing/Writing Functional Specifications *	56	CAD Design and Layout *	29
Safety in Product Design *	52	Product Liability *	24
Leadership	50	Quality Function Deployment *	17
Standard and Regulations *	49	Other	13

Table 1: Subjects Taught (2005 Data)

Collectively, the results from this survey question suggests that capstone courses nationwide are increasingly incorporating more subject matter, either formally or informally, and that there is an emphasis on professional skills to aid students in their capstone project and their career paths post-graduation.

The data on the classroom aspects of capstone design as a whole show some constancy in structure, while also indicating a greater number and variety of courses, an emphasis on professional skills, and increased student and departmental teamwork. As in 1994, respondents in 2005 tended to offer class and project in parallel, lasting either one or two semesters. Within the courses, however, subjects often taught in 1994 were taught more frequently still in 2005, with an increased emphasis on subjects such as communication, teamwork, and leadership. Finally, project teams of single students only occurred less often in 2005 than in 1994, while interdepartmental teams became more frequent.

3C. Faculty Involvement

This section details information related to faculty involvement in capstone experiences. The specific data discussed include percentage of faculty involvement, role of faculty, and student to faculty ratios.

Figure 8 shows the faculty involvement in capstone experience. The 2005 data are based on the reported number of faculty involved in the capstone course as a fraction of the total number of faculty in the department. While the overall distribution of the 2005 data is similar to that from 1994, the increases in the extreme ends (1-20% and 80-100%) are interesting, perhaps signifying a bifurcation of departmental approach to capstone involvement. A full 16% of departments responding involve 100% of their faculty in their capstone experience.

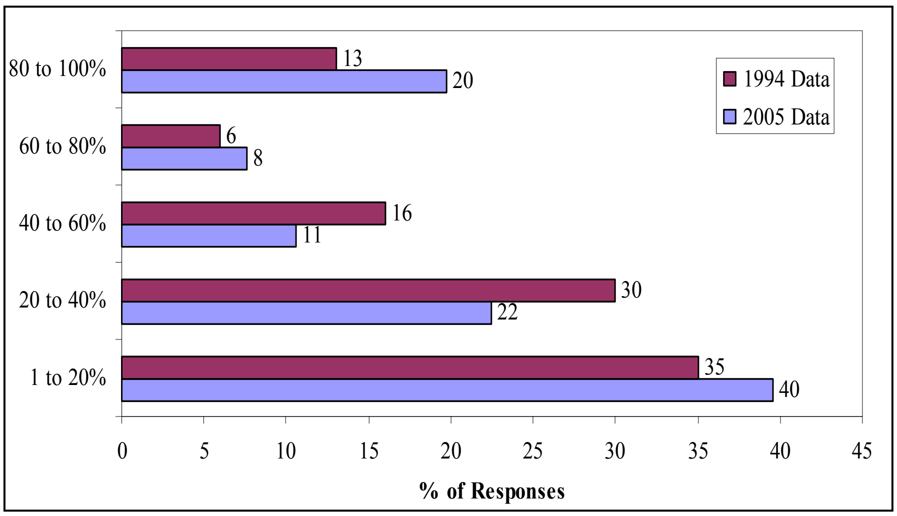


Figure 8: Percent of Faculty Involved in Capstone Experience

In addition to reporting the number of faculty involved with the capstone course overall, many 2005 survey respondents also indicated the number involved in the project component and the formal instruction, as two distinct options. Figure 9 shows the comparison results for both project involvement and formal instruction involvement. The project data follow a similar

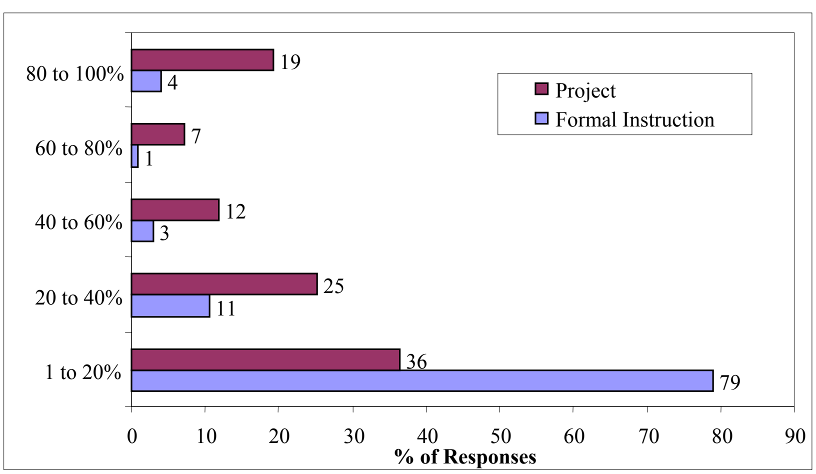


Figure 9: Percent of Faculty Involved in Capstone Project and Formal Instruction (2005 Data)

distribution to the overall course (see Figure 8), with the majority of departments involving either <40% or nearly all of their faculty. Given the nature of most college courses, the fact that 79% of respondents involve one or very few faculty in the formal instruction is not surprising; what is worth noting is the small, but not insignificant, number who involve 20-100% of their faculty even in the instructional component.

Figure 10 highlights the ways in which faculty participate in capstone projects. As was true in 1994, the majority of respondents consider the faculty as mentors, followed by consultants and evaluators. In addition to requesting faculty roles, this question also inspired respondents to comment on the extent to which a single person coordinated the entire capstone course. According to the 1994 data, 27% of respondents noted that a single faculty member coordinates the departmental capstone course. In the 2005 survey, 16% of respondents specifically volunteered that they oversaw the entire capstone course; this percentage increases to about 24% when cross-checked against the data underlying Figure 8. Clearly, faculty continue to have varied roles in capstone courses, and a sizable minority of capstone courses are still coordinated by a single person.

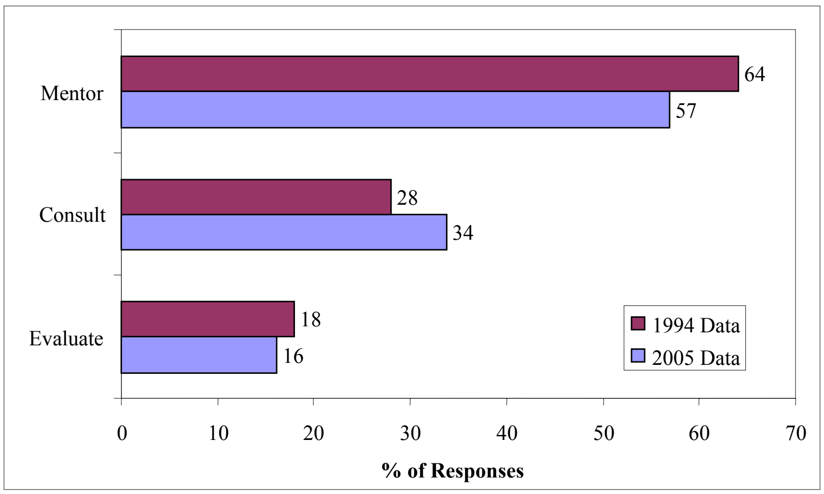


Figure 10: Faculty Role in Capstone Involvement

Figure 11 illustrates the student to faculty ratio for capstone courses. Both the 1994 and 2005 surveys asked respondents to provide the average number of students in the capstone design course; these responses were then divided by the number of faculty involved with the capstone course. As such, the data do not differentiate between overall course, project, and formal instruction; as was discussed for Figures 8 and 9, however, the reported faculty involvement overall followed a similar

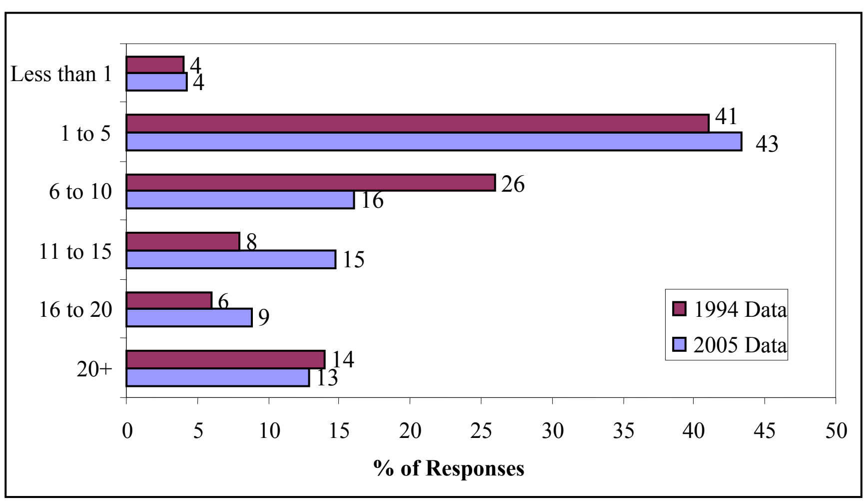


Figure 11: Student to Faculty Ratio in Capstone Courses

distribution to faculty involvement in projects. As is clear in Figure 11, the reported 2005 student to faculty ratios are similar to those reported in 1994. The decrease in the 6-10 range is countered by an increase in the 11-15 and 16-20 ranges, suggesting that at least in some departments student numbers are increasing and/or faculty involvement is decreasing. From an educational perspective, it is encouraging to see the continued strong presence of the 1-5 range, as well as the cases with more faculty than students. Not surprisingly, more than 60% of the departments with a student-faculty ratio of <1 involve more than 80% of their faculty in their capstone courses.

In short, data on faculty involvement seem to lean towards extremes. Respondents in 2005 show an increased tendency to involve either very few or most of their faculty in the capstone course. The large majority of 2005 respondents have only a few and perhaps even one faculty member for formal instruction, but nearly one-fifth include 20-100% of faculty. Distribution is more even for the project portion, but the data suggest that most often, less than half of the faculty will be directly involved in projects. Mentoring remains the most usual way in which faculty are involved, though the question on faculty roles prompted about a quarter of respondents to both surveys to note that a single person oversaw every aspect of their design course. In student to faculty ratios the 1-5 range is still the most prevalent, but the 2005 data show an increase in more students per faculty member has developed even while a consistent 4% of respondents involve more faculty members than students overall.

3D. Project Information

This section covers project-specific information for capstone courses. Of particular interest is project sourcing, number of projects per course, number of teams per project, number of students per team, and number of project hours per week.

Figures 12A and 12B depict where survey respondents found their projects. The results are shown in two separate graphs to reflect the different wording on the two surveys. While project sourcing was evenly matched both industrially and internally in 1994, the 2005 data show a decided shift toward external project sourcing, with industry at 71% and external competitions at 24%.

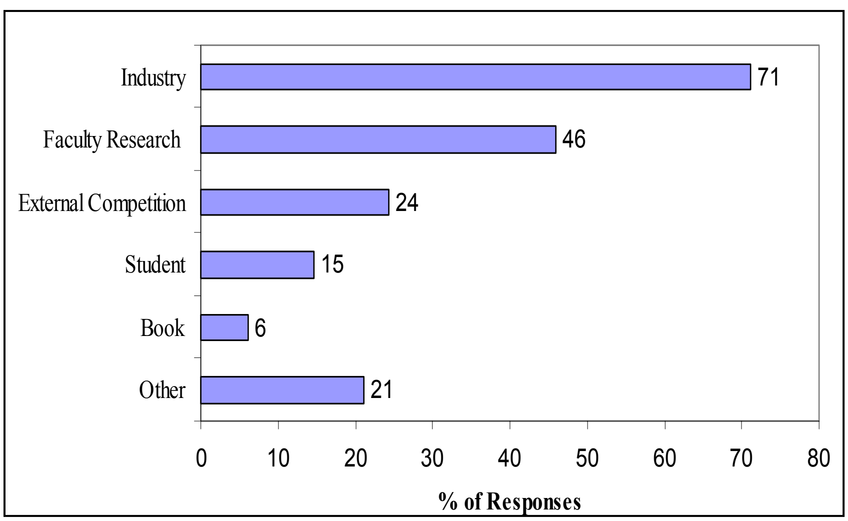


Figure 12A: Sources of Capstone Projects (2005 Data)

Interestingly, while many respondents to both surveys selected multiple answers to the question, 30% of 2005 respondents indicated that projects were obtained from only one source. Of those who selected only one option, industry was the most frequent choice. Comments in the 2005 survey followed several trends: some noted that community involvement or specifically community service projects were common, while others emphasized that project sources varied within the department.

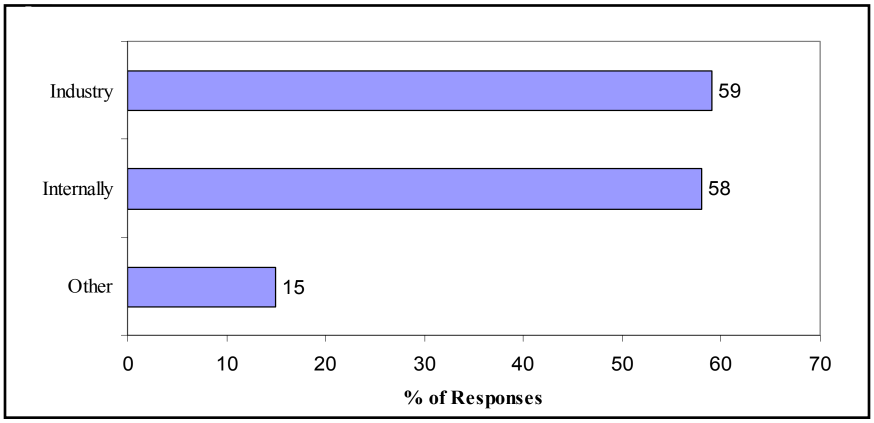


Figure 12B: Sources of Capstone Projects (1994 Data)

Figure 13 shows the number of projects per course cycle. A comparison of the 1994 and 2005 data reveals a sizable increase in the 2-5 project range accompanied by a decrease in both the single project and the 16 or more projects range. Note that the average number of projects per department is 8.1 and the median is 5.0 for the 2005 data.

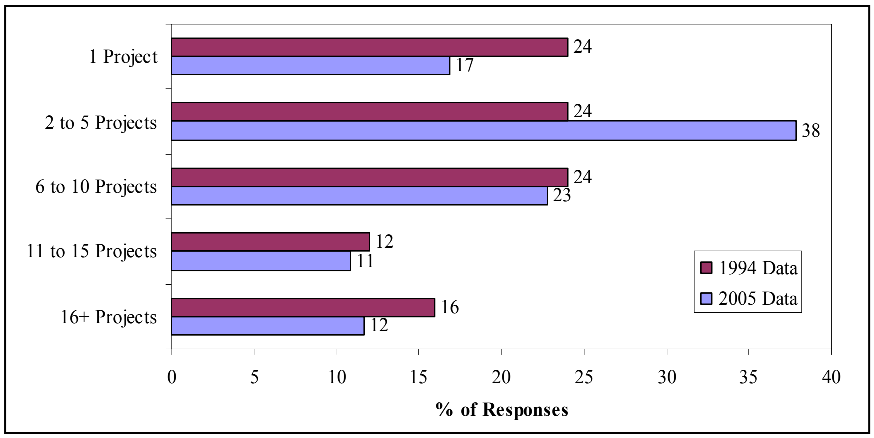


Figure 13: Number of Projects per Course Cycle

When reporting the 1994 data, Todd et al.[3] suggested that they planned to correlate the number of projects per course cycle with the number of students in each course cycle. Figure 14 illustrates these results for the 2005 data, indicating that there is little correlation; indeed one cannot conclude that a larger number of students maps to a larger number of projects. The few points that reflect large project numbers for small student numbers likely include multiple shorter-duration projects during a single course.

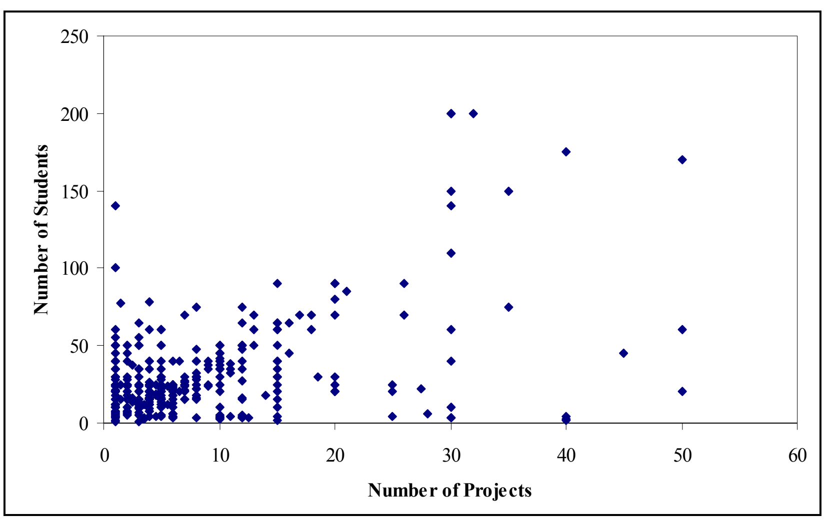


Figure 14: Number of Students Versus Number of Projects per Course (2005 Data)

Figure 15 shows the number of teams assigned to each project. In the 2005 data, the "1" response refers to a response of exactly 1, whereas the "1 to 3" range includes all responses ≥ 1.5 and < 3.5. Similarly, the other ranges include rounded values as well (i.e. the "4 to 6" range includes all values ≥ 3.5 and < 6.5). When respondents actually reported a range (such as "1-4"), the input was averaged and the resulting value was categorized accordingly. As is evident in the figure, the practice of assigning a single team to a given project is not only still the norm, but is even more typical than it was a decade ago. Some departments still assign more than 1 team per project and a small number noted that all teams in a given class work on the same project, though that practice has decreased since 1994.

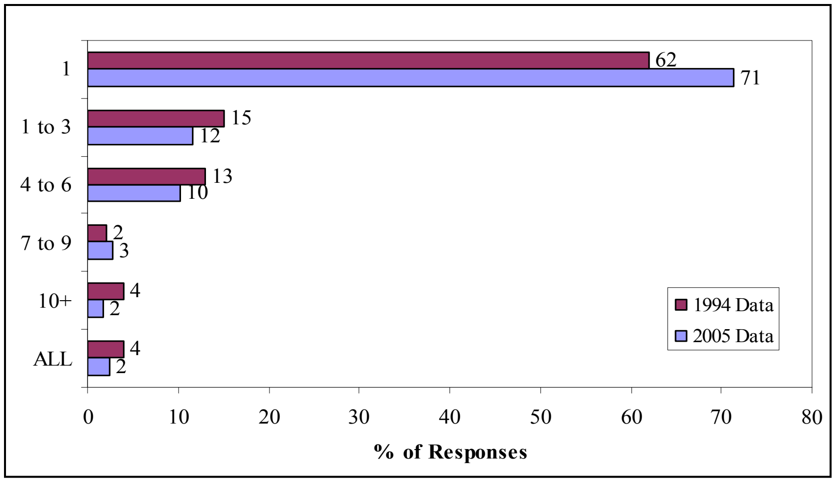


Figure 15: Number of Teams per Project

Figure 16 illustrates the number of students per team. As for Figure 15, the "1" response for the 2005 data refers to input of exactly 1, the "1 to 3" range includes responses ≥ 1.5 and < 3.5, and so on; respondent input was averaged as necessary to yield a single value for categorization. The fact that there are so few reported single person teams in 2005 does not imply that almost no departments utilize single person teams (a result that would conflict with the data in Figure 3), but rather that only very few departments utilize *solely* single person teams. Since respondents were asked to report the average number of students per team, the presence of multi-person teams increased their average to more than 1. This is in keeping with the data behind Figure 3, in that only 2% of those respondents selected *only* the "Individual" option.

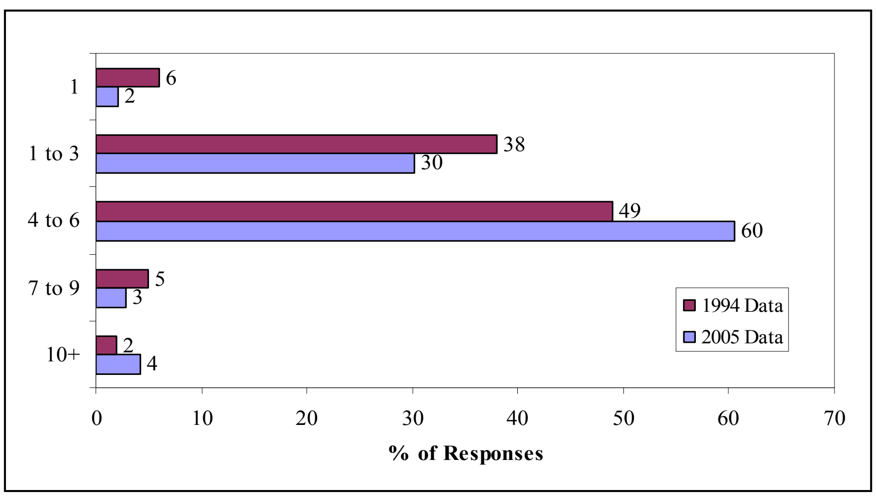


Figure 16: Number of Students per Team

While the overall distribution of the 2005 data is similar to that of the 1994 data, the sizable increase in 4 to 6 person teams and the corresponding decrease in 1 to 3 person teams are worth noting. These trends suggest an increased emphasis on teamwork, particularly in medium-sized teams, and may reflect an increased complexity of capstone projects, given that the duration of capstone courses (see Figure 5) has not changed substantially in the past ten years.

As shown in Figure 17, respondents indicated how many hours per week students work on projects. While the two surveys offered possible answers in different time ranges, both data sets reveal a leaning toward more student work, upwards of 7 hours per week, rather than less. In interpreting these data, it is important to note a slight discrepancy in wording between the two surveys: where the 2005 survey inquires about the hours outside class time students are "expected to work," the 1994 survey asks how many hours outside the classroom are "allocated," which may have been interpreted as time officially set aside for the course. In 1994, the comments received suggested that students were "expected to complete the job regardless of how much time it took"[3]. While there was no space for comments on the corresponding 2005 question, the sizable percentage of respondents indicating 10 or more hours a week suggests that this expectation has not changed in the years since the first survey and, if anything, has increased.

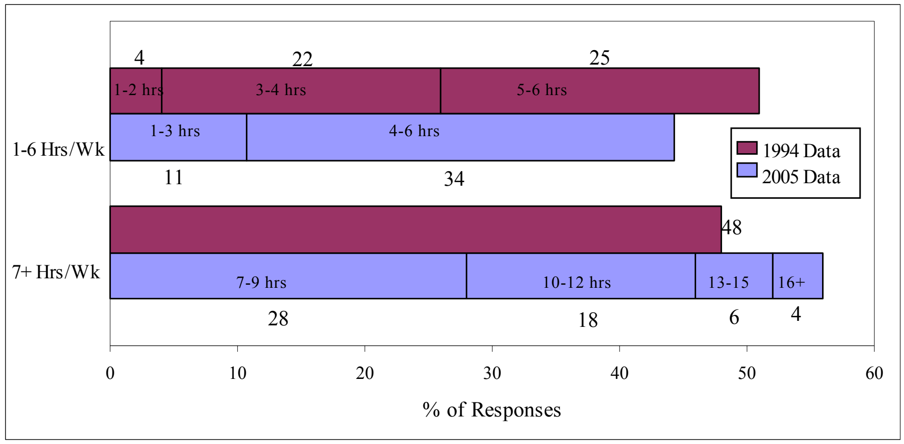


Figure 17: Number of Project Hours per Week

An overall examination of project structure shows that many aspects are the same in both the 1994 and 2005 data, perhaps suggesting that many departments have found satisfactory project arrangements and maintained them. Most departments, for instance, still have students spending upwards of seven hours a week on their projects, and a large majority have retained the practice of assigning one team per project, most often with 4-6 students on a team. The 2005 results show an increased tendency for two to five projects per capstone course cycle. The most significant change is an increased emphasis on external project sourcing, with industry and external design competitions accounting for the vast majority of current projects.

3E. Funding Information

This section discusses funding details for capstone courses, with a focus on project funding. Specific data reported include sources of funding and strategies for funding. Additional funding information specific to industrial sponsorship is included in Section 3F.

Sources of funding are illustrated in Figure 18A. In both 1994 and 2005, the institution is the most frequent provider. Students in 2005 seem to be paying for projects in fewer of the responding programs than they did in 1994; outside sponsors, however, have retained a fairly constant role, funding at least some projects for approximately half of the respondents.

Comments from 2005 respondents noted alumni gifts, grants, and departmental budgets as other sources of funding.

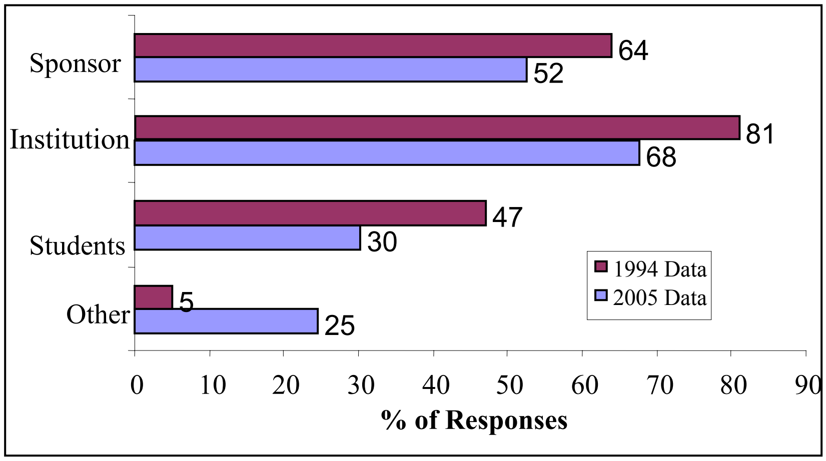
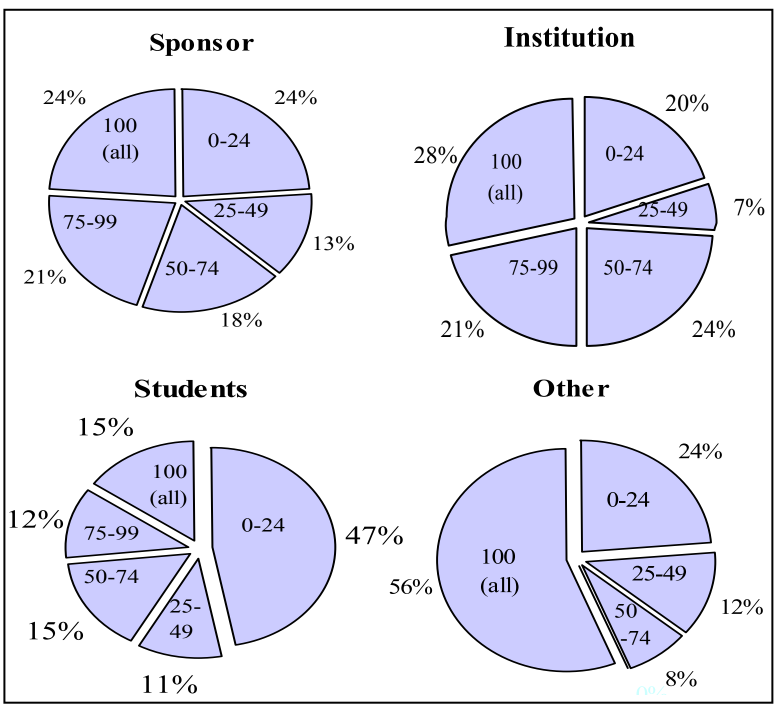


Figure 18A: Sources of Project Funding

The more substantial increase in respondents who marked "Other" may be a result of alternate funding sources, but may also be due to differences in the pools of respondents in both 1994 and 2005. As shown in Figure 1, the 2005 survey included fewer respondents from mechanical and industrial engineering and more from chemical, computer, and "other" engineering disciplines than did the 1994 survey; the design projects for these non-manufacturing departments may not include a physical/built final product, so may incur fewer costs. (The wording of the two questions reflects this difference: the 2005 survey asked about funding for "direct project costs" where the 1994 survey specified funding for "hardware and materials."[1]) Indeed, many 2005 respondents checked "Other" and commented that their design projects did not require funding.



Figures 18B-18E: Percentage Breakdown of Project Funding (2005 Data)

Respondents to the 2005 survey were also asked to indicate the percentages of projects covered by each source of funding; the results are shown in Figures 18B-18E. (The responses were grouped into quartiles, with those answering 100% receiving a separate category. The numbers inside the pie chart represent the quartile ranges of percentage of funding from a given source. The numbers outside the pie charts reflect the percent of respondents who reported values in this category.) Interestingly, the 100% category appears on every pie chart, implying that many institutions receive all of their funding from a single source. Students are most often expected to shoulder the smallest percentage of project cost, while the amount covered by sponsors and institutions appears to vary widely.

In Figure 19, project funding is examined from another angle, as respondents were asked how a sponsor funds a program. Responses to this question, which focused on funding that came from outside the university, appear to have remained remarkably consistent over the last ten years. As in 1994, the 2005 data show that sponsors are more likely to fund the project directly, rather than the institution, but providing funding to both is also frequent. Perhaps the most notable are the comments accompanying the 2005 "Other" responses, where as in earlier responses many marked that funding questions were not applicable to their program. Others, however, specified that their program lacked a set system for managing sponsorships, or expressed dissatisfaction with the current methods of funding. A few responses suggested that it was not appropriate to accept outside funding for a design project. The high number of "Other" responses, along with the heated nature of the comments, seem to indicate that project funding can be a frustrating aspect of capstone courses.

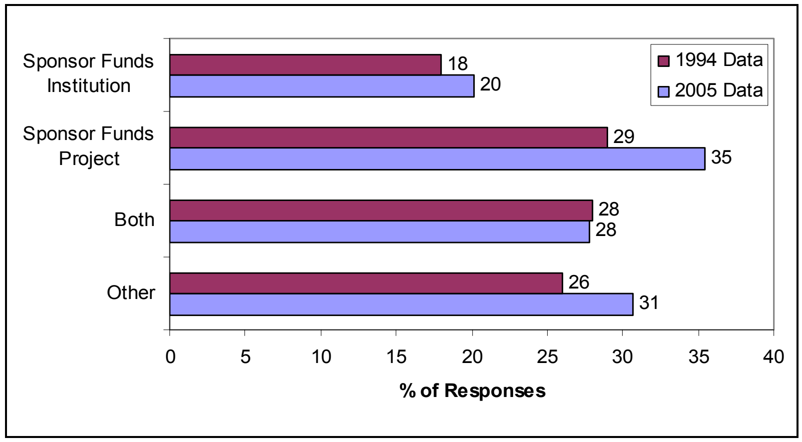


Figure 19: Strategies of Project Funding

As with data on projects in general, many aspects of project funding have remained constant between 1994 and 2005, including source of funds and systems of sponsorship. Institutions still fund projects most frequently, and industry remains a resource for over half of respondents. (There was an increase in "Other" sources of funding in 2005, which may be attributed to a higher number of 2005 respondents whose projects require no funding.) Sponsors were still more likely to fund a project directly; this tendency became more pronounced in 2005, while funding both project and institution remained a strong option. Despite this general constancy of practice over the years between surveys, comments in 2005 stood out as indicating a strong dissatisfaction with current systems of funding.

3F. Industry Sponsorship

Since industry sponsorship is an increasingly common component of capstone experiences[13-16], one section of the 2005 survey was specifically dedicated to questions about projects with industry. Only those respondents who engaged in industrial projects (see Figure 12A) responded to this section. The results of their answers, in comparison to 1994 data, are presented below.

Continuing the funding theme, Figure 20 depicts the level of financial support from industrial sponsors. Results are relatively constant across the two surveys, with many projects receiving less than $500 from the sponsoring company. Nearly a quarter of 2005 respondents selected "Variable" (which was not an option on the 1994 survey) reinforcing earlier responses that suggest a wide range of funding even within a single program. For those who received $5,000 or more, the 2005 data were divided into several categories, shown but not labeled on the graph due to their small percentages. In the largest of these, 5% of respondents answered that at least one of their projects received $40,000 or more. Comments received from the 2005 survey were similar to earlier questions on funding, in that many programs, if accepting funding at all, have no set standard and have sponsorship levels largely dependent on the participating company.

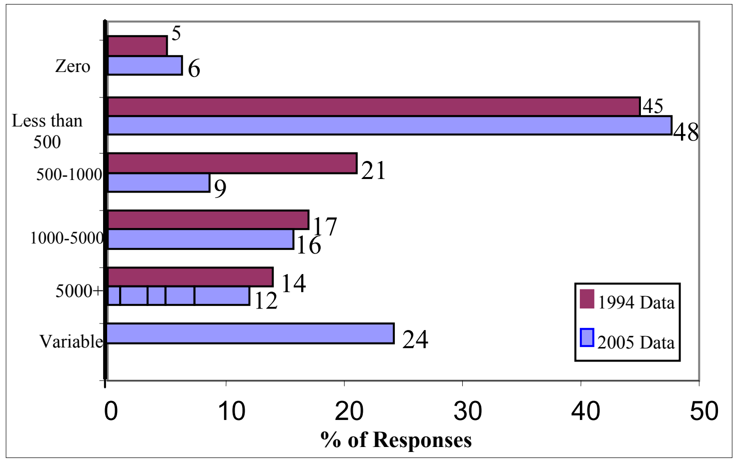


Figure 20: Level of Sponsor Support

Another question specifically for programs with industry sponsorship focused on the location of project funding, with results shown in Figure 21A. Respondents were given the choice of "Locally" (within 20 miles), "Regionally" (20-100 miles), or "Nationally" (more than 100 miles). Local sponsors remained the largest source of funding, with the 1994 data suggesting that these sponsors provided a convenient and ultimately more satisfying design experience due to ease of contact.[3] Many programs, however, seem to have reached out to national sponsors over the last decade, with almost half of 2005 respondents finding sponsorships more than 100 miles away from their institution.

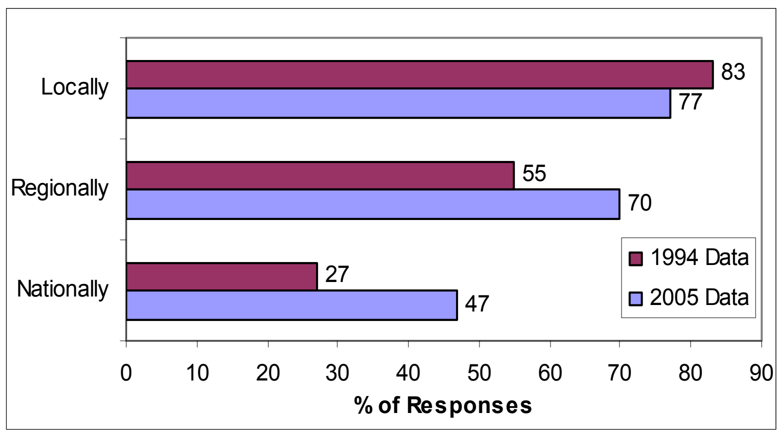
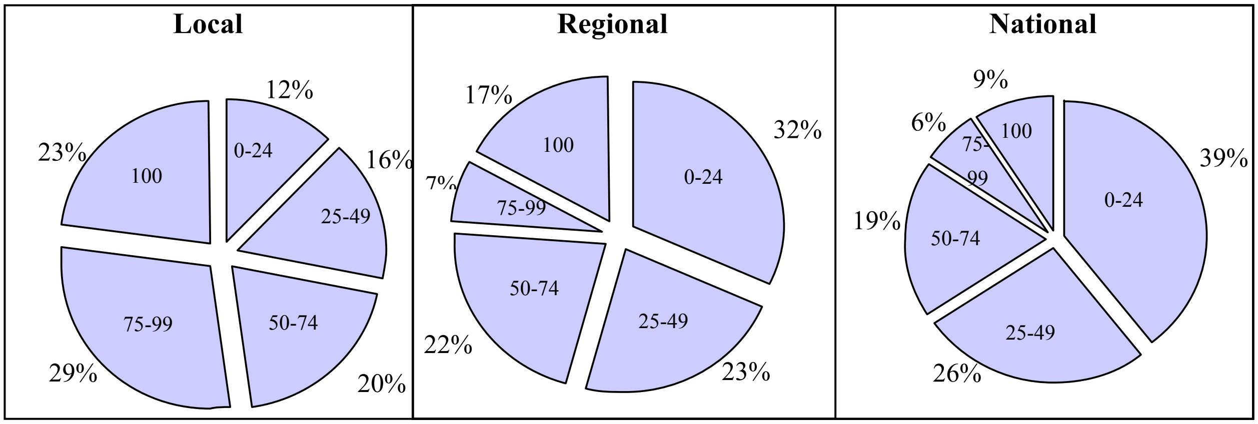


Figure 21A: Location of Project Funding

Respondents to the 2005 survey were also asked to indicate the percent of sponsors from local, national and regional sources; the results are shown in Figures 21B-21D. (Ranges within the pie chart represent percent of sponsors located within the designated region: local, regional, national. Numbers outside the pie chart represent the percent of respondents who reported values in this range.) Those respondents who marked "Locally" tended to obtain most of their sponsors locally: nearly a quarter had only local sponsorships, and more than half had at least 75% local sponsors. Conversely, few respondents who marked "Nationally" listed it as their only sponsor location, and most said that sponsors more than 100 miles away were a small percentage of their sponsors. Together with the results in the bar graph, the data suggest that local organizations remain the bastion of industry sponsorship, but respondents are increasingly connecting with industries further afield.



Figures 21B-21D: Percentage Breakdown of Sponsors by Location (2005 Data)

Respondents that had some projects sponsored by industry were also asked about the amount of contact between project teams and their sponsors; the responses are presented in Figure 22. In both the 1994 and 2005 data, weekly interaction is the most frequent response by at least a small margin; in fact, the usual level of contact has remained divided between weekly, monthly and beginning and final meetings. In both surveys, the constant level of "Other" responses and the number of respondents who checked multiple boxes suggest that many respondents have different levels of contact for different projects. The comments from 2005 supported this conclusion: many wrote that the amount of contact depended on the client and the demands of the project. Several noted that beginning, interim, and final meetings were common, and a small percentage (1.5%) of 2005 respondents wrote that some teams met with sponsors more often than once a week. In short, contact between sponsors and students varies now as it did ten years ago.

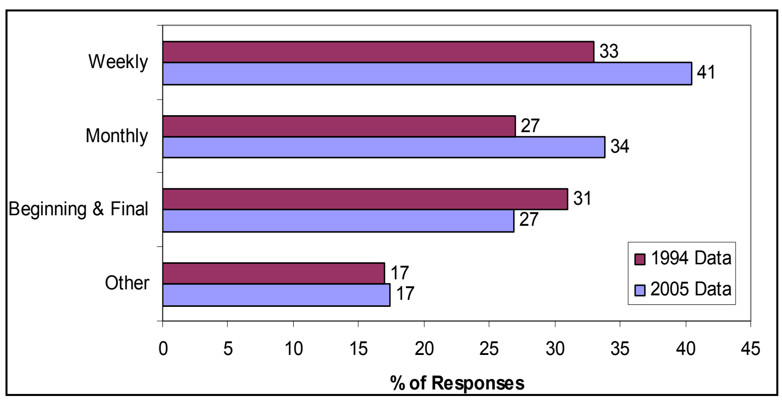


Figure 22: Amount of Contact with Sponsor

Figure 23A shows the results of a question regarding ownership of intellectual property. While sponsor ownership was the most frequent in the 1994 data, the number of sponsors possessing at least part of the intellectual property has increased still further from 40% to 64% of respondents in 2005. Interestingly, ownership by both institutions and students has remained fairly constant, and each is about equally likely to have some portion of intellectual control. Comments from the 1994 survey, which allowed respondents to check "Other," found that many had worked out a different type of arrangement for intellectual property, or had no arrangement at all.[3] Comments from both surveys suggest there is great variation but that the level of sponsorship was also a factor.

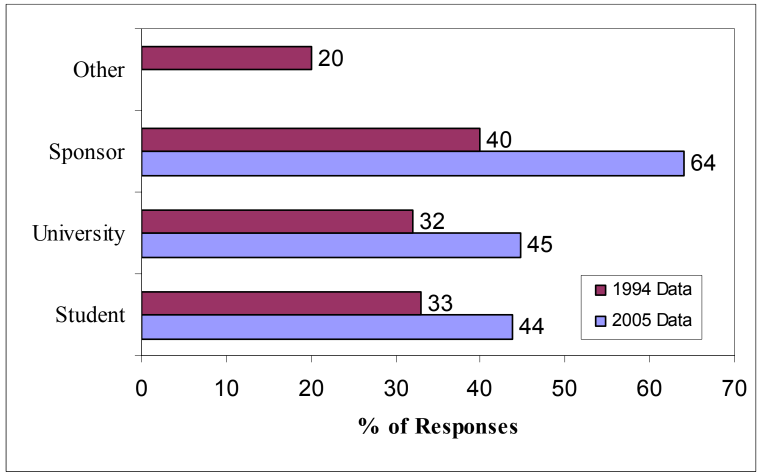
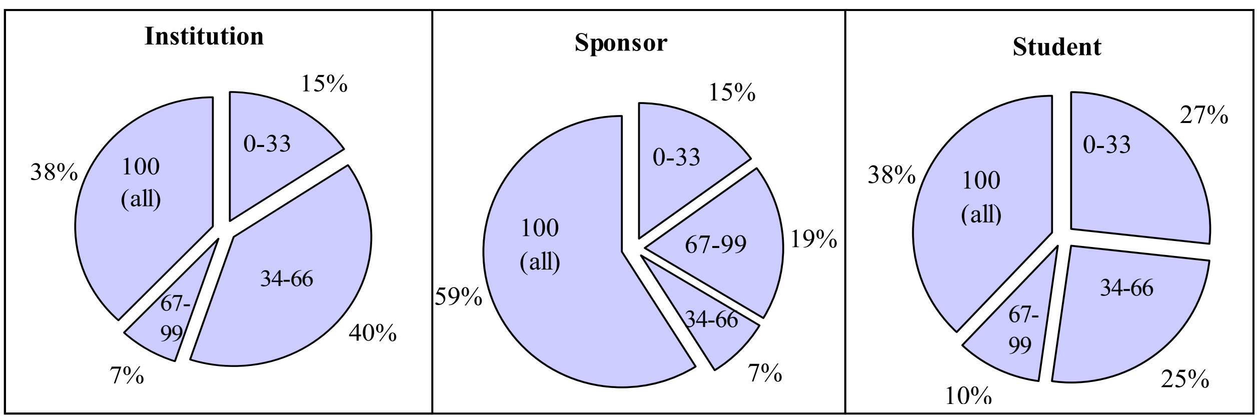


Figure 23A: Intellectual Property Ownership

Both the 1994 and 2005 data sum to more than 100%, suggesting that IP rights may often be shared. This possibility was examined further in another 2005 survey question, which asked respondents to note the percentage of ownership granted to each entity. The results of this breakdown are indicated in Figures 23B-23D; as before, the numbers inside the pie chart represent the range of percent ownership by a given entity and the numbers outside the pie chart reflect the percent of respondents who reported values in this range. As is clear in Figure 23C, sponsors are distinctly more likely to own all of the intellectual property if they own any. Institutions and students appear to have a wider range of partial ownership, with full ownership going to either entity only 38% of the time. Otherwise, the respondents grant varying degrees of ownership, most often one to two thirds of the intellectual rights, to students and institutions. In total, variety seems to be the largest theme of intellectual property, but the emphasis on increased ownership by sponsors should not be overlooked.



Figures 23B-23D: Percentage Breakdown of Intellectual Property Ownership (2005 Data)

In short, the results in this section suggest that industry sponsorship plays an ever larger and more varied role in capstone design. Industry sponsors offer financial support ranging from nothing to over $40,000 per project, with a majority of schools from both surveys selecting less than $500 per project, but nearly one quarter among the 2005 respondents noting that support varies. There has been an increase in national and regional affiliation even while local sponsorships remains prevalent. Contact between sponsors and students varies widely between institutions and even within departments, but the data indicate a general increase in weekly and monthly contact. Intellectual property is also a disparate issue, yet industry sponsors are the most frequent owner of IP, and if they own any, they are most likely to own it all.

4. Conclusions

As a successor to the 1994 "Nationwide Senior Design Course Survey"[1], this 2005 survey of engineering capstone design courses was motivated as a means to document current approaches, identify trends, and share best practices with fellow educators. To that end, we developed an online survey based on its 1994 predecessor, sent it to colleagues for review, then invited all ABET-accredited United States engineering programs to participate. The results, processed digitally, returned a response rate of 66% among institutions and 26% among programs, for a total of 444 programs from 232 institutions. Although the 2005 survey originally asked 57 questions, the results presented in this paper are largely from the questions that overlapped with the 1994 survey, so as to highlight changes in the past decade.

The data from both surveys are presented graphically throughout this paper, with accompanying discussion. The results are divided into sections on respondents, course logistics, faculty involvement, project information, funding details, and industry participation. While the most outstanding trends are reviewed below, a more in-depth examination can be found in the section conclusions throughout the paper.

Data of note were found in all aspects of capstone design, from project and classroom procedure, to funding and sponsorship, to the profile of the respondents themselves. As in 1994, these respondents represented a fairly even distribution among departments, with a 28% overlap between the two surveys. The 2005 responses on course structure suggest that a one-to-two semester course with simultaneous class and project components remains popular, while course content shows a greater breadth and a leaning towards professional skills. In the project area, most schools still assign one team per project, with an increased tendency toward 4-6 students per team and 2-5 projects per course cycle. External project sourcing, either through industry or design competitions, has increased in frequency and is the most common approach. Institutions tend to involve either most or very few faculty in the course in general, and few in formal instruction, with a fairly consistent majority maintaining a student to faculty ratio in the 1-5 range. Direct costs are most often covered by the institution, though industry sponsorships have become more frequent. Among the increased percentage of institutions with industry sponsors, national and regional affiliations are growing, sponsors are more often granted some or all intellectual property rights, and sponsoring companies tend to have more frequent contact with their student teams. Additionally, any review of the trends cannot fail to mention a predominant theme consistent from 1994 to 2005: the tremendous variety between schools, departments and even projects within a given department. Capturing such variation with a single survey is, as was noted by Todd et al.[3], a difficult task.

The combination of the trends reported here and the difficulty of characterization nationwide argue for a final conclusion: the importance of further research on general practices within capstone education. Indeed, capstone courses are a widespread component of engineering education that offer a positive learning opportunity for students: respondents to the 2005 survey reported an average faculty rating of 8.6 out of 10 and an average student rating of 8.5 out of 10 when asked about the educational value of their capstone course. Moreover, the prevalence of institutions with established means of assessing their capstone courses (90% of 2005 respondents reported having some method of determining capstone course success) suggests that faculty are well-versed in providing information about their courses. Another follow-up survey in five to ten years, perhaps coupled with a longitudinal effort, would well serve capstone design education.

5. Acknowledgements

We gratefully acknowledge the many engineering faculty nationwide who contributed their time and responses to the 2005 capstone survey. Our apologies to those who did not receive the survey request. We also extend special thanks to the architects of the 1994 survey for laying the foundation of capstone course understanding and to Bob Todd, Keith Stanfill, Steve Beyerlein, Catherine Skokan, Dwight Wardell, and Jack Zable for assistance with the 2005 survey development.

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