Capstone Design Courses and Assessment of ABET EC 2000: A National Survey

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Abstract

This paper describes the results of a nationwide survey concerning the assessment of ABET EC 2000 Criteria 3 (a-k) and 4 learning expectations within the context of a comprehensive design project. In fall 2001, engineering disciplines from all institutions in the U.S. with accredited engineering programs were asked how engineering programs use the senior capstone design project to assess competencies related to capstone design. The institutional response rate for the study was 43% (n = 119) of the 274 institutions with accredited programs. A total of 298 surveys were received across programs. All major engineering disciplines were represented. Survey results were organized into three categories: Capstone Project Information, Capstone Assessment Development, and Collaboration Interest. The gap between outcomes respondents report appropriate for assessment and those actually assessed indicate that many faculty may be uncertain about the task of developing quality assessments for ABET engineering learning outcomes based on capstone design projects. Responses from 65% of the faculty respondents indicate a willingness to collaborate with colleagues across the country on capstone design assessment, development and use. Descriptive statistics summarize the results.

I. Introduction

The quality of teaching and learning in programs preparing undergraduate students for engineering practice is a focal point of national interest [1]. Reasons for the concern include declining enrollment in undergraduate engineering programs and the need to increase and expand the professional competency of the engineering workforce. Engineering design in particular, has received considerable scrutiny. Proposals to enhance engineering design education have included the development of design expectations across the curriculum, team-based learning activities, and assessments to gauge student attainment of outcomes [2], [3].

One aspect of design education now receiving attention is the design capstone experience. Todd, Magleby, Sorensen, Swan, and Anthony conducted a study in 1995 that included a survey of capstone engineering courses throughout North America in order to understand current practices in capstone education [4]. The study found that many engineering programs were using senior design/capstone-type courses to help prepare students for engineering practice, and a significant number of institutions engaged industrial clients to sponsor capstone projects. In addition, a number of schools were using undergraduate team based projects, with a few using inter-departmental undergraduate teams from different disciplines. These project driven activities required heavy faculty commitment, but respondents felt the investment was valuable in producing competent engineering graduates. The study did not investigate assessment practices within the capstone course.

Engineering Criteria 2000 (EC 2000), now being implemented by the Accreditation Board for Engineering and Technology (ABET), mandate outcome based assessment of graduating engineers' abilities to apply technical and other professional skills to solve real-world engineering problems [5]. Criteria 3 and 4 of EC 2000 in particular, require integration and assessment of key performance skills within the context of a comprehensive design project. The specific outcomes for Criteria 3 and 4 read as follows:

"Criterion 3 Outcomes that must be demonstrated:

a- Apply knowledge of mathematics, science and engineering.

b- Design, conduct experiments, analyze and interpret data.

c- Design a system, component, or process to meet desired needs.

d- Function on multi-disciplinary teams.

e- Identify, formulate, and solve engineering problems.

f- Understand professional and ethical responsibility.

g- Communicate effectively.

h- Understand the impact of engineering solutions in a global/societal context.

i- Recognize the need for and an ability to engage in life-long learning.

j- Understand contemporary issues.

k- Use the techniques, skills, and modern engineering tools necessary for engineering practice.

Criterion 4 Design constraint considerations in capstone experiences:

a- Economic;

b- Environmental;

c- Sustainability;

d- Manufacturability

e- Ethical;

f- Health and Safety;

g- Social; and

h- Political" [5].

For the past six years, a team of institutions in the Pacific Northwest has collaborated to develop engineering design competencies for each year of undergraduate engineering education [6], [7], [8], [9], [10], [11], [12]. To date the work has included design competencies for the first 2 years of undergraduate engineering education and an assessment system to evaluate student attainment of competencies as entering juniors. Anecdotal evidence indicates several institutions across the country have piloted or adapted the assessment system for programmatic feedback. Some programs are using the assessment system as part of their continuous improvement process that also support ABET accreditation.

To enhance our understanding of assessment in the context of design capstone courses, a national survey of all accredited engineering programs was conducted in the fall of 2001. The investigation focused on how engineering programs use the senior capstone design project to assess competencies related to ABET outcomes. This paper summarizes and analyzes the results from the survey and presents timely information on the role of capstone design projects in assessment of ABET Criteria 3 and 4. It is hoped that engineering programs across the country can use these results to inform and improve capstone design experiences for students.

II. Survey Instruments and Responses

A. Instrument Development

During spring, 2001, a team of assessment and evaluation professionals and engineering faculty at Washington State University and the University of Idaho, developed initial survey questions to determine use of assessment in capstone design projects. The survey was subsequently piloted at a meeting at Western Michigan University. Administrators and professors from a variety of engineering disciplines participated in the pilot and provided feedback.

After incorporating revision suggestions from the pilot, the final survey instrument consisted of 13 items, asking a range of questions about an engineering program. Items also asked for information concerning the characteristics of the capstone project including its duration, importance in the undergraduate curriculum, and practices using the capstone design projects to fulfill EC 2000 Criterion 3 and Criterion 4 requirements.

B. Procedures

On September 14, 2001 surveys were mailed to the deans of the 274 institutions with accredited engineering programs listed in the ASEE Profiles of Engineering and Engineering Technology reference [13]. Each dean received a packet containing multiple copies of the following items: cover letter, survey, informed consent form, and stamped return envelope. Deans were asked to forward the survey packets to the course coordinators of the capstone design projects in each of their undergraduate engineering disciplines. These disciplines typically include mechanical engineering, electrical engineering, civil engineering, civil engineering, computer engineering, and environmental engineering, but did not exclude the smaller programs. Given the events on September 11 in New York, Washington, D.C., and Pennsylvania, and related impacts on people and mail delivery, two months elapsed before further requests were attempted. An email follow up was sent to prompt non-respondent institutions to complete an on-line version of the survey.

C. Description of Sample

As of January 18, 2002, 298 responses were received from 119 institutions with accredited engineering programs; a 43% institutional response rate. On average, 2.5 program responses per institution were received, with 4 or more responses from each of 27 institutions. All major engineering disciplines were represented with responses from 15% to 30% of the programs within a discipline. This institutional response rate is comparable to other surveys identified in the engineering literature [4].

Figure 1: Institutional Responses by Geographic Region. Responses were categorized by geographic region consistent with demarcation outlined in the U.S. census of population [14]. These regions included *North East* (ME, VT, NH, MA, CT, RI, NY, PA, NJ); *South* (MD, DE,

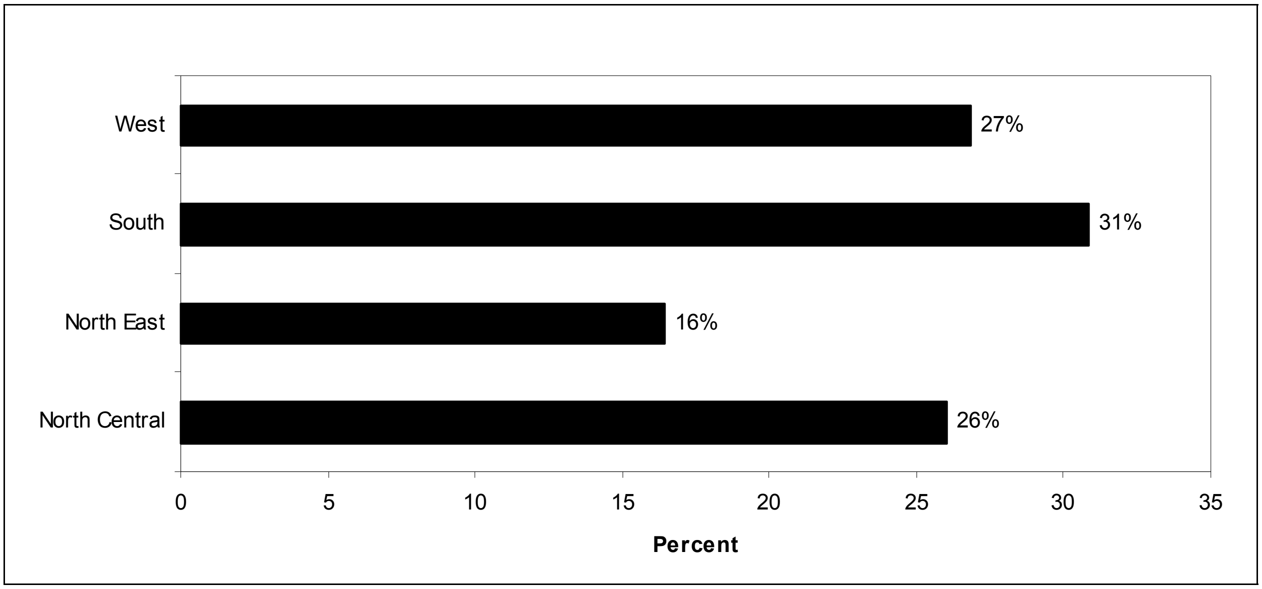

Figure 1. Percentage of Responses by Geographic Region of U.S.

VA, WV, KY, NC, SC, TN, GA, MS, AL, FL, LA, AR, OK, TX); *North Central* (ND, SD, NE, KS, MN, IA, MO, WI, IL, MI, IN, OH); and *West* (MT, WY, ID, CO, UT, WA, OR, NV, CA, AZ, NM, AK, HI). The number of responses by region included North East (n = 49), South (n = 92), North Central (n = 77), and West (n = 80). Response rates were fairly evenly divided among the four regions as shown in Figure 1. The largest number of responses came from the southern region of the country, while the fewest returns came from the North East.

Figure 2: Departmental Responses by Discipline. A cross section of the engineering disciplines was represented by the survey. As expected, more total responses came from the larger

engineering disciplines than from those disciplines that have a smaller number of accredited programs. Of the 298 total responses, the largest percentages were from the following

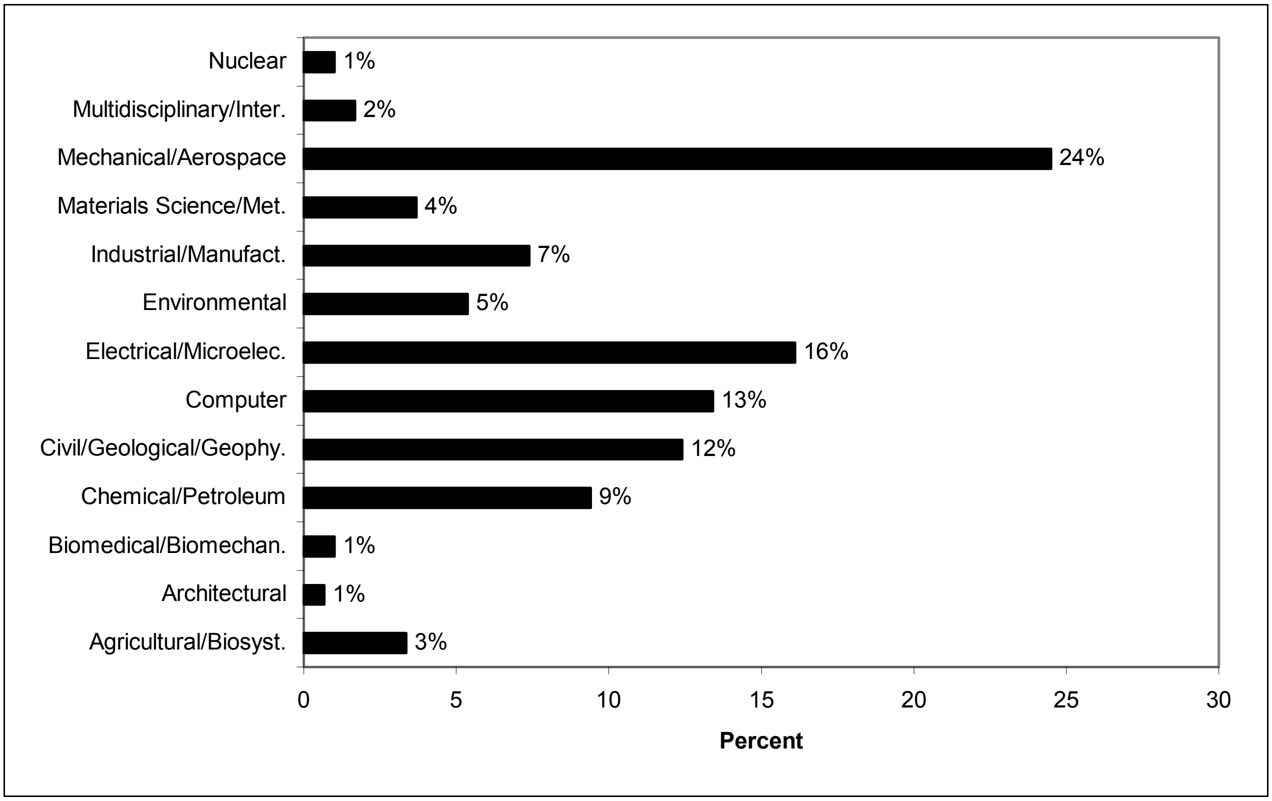

Figure 2. Departmental Responses by Discipline

disciplines: mechanical engineering 24% (n = 73), electrical engineering 16% (n = 48), computer engineering 13% (n = 40), civil engineering 12% (n = 37), chemical engineering 9% (n = 28), industrial engineering 7% (n = 22), environmental engineering 5% (n = 16), and materials engineering 4% (n = 11). The remaining disciplines each had 10 or fewer responses.

Figure 3: Role in Capstone Design. Respondents were asked to identify their role in the senior design capstone projects. Ninety-five percent (95%, n = 283) of the 298 respondents identified with one of three categories. Specifically, respondents classified themselves as (a) intimately involved in the course as the instructor, capstone coordinator or advisor 83% (n = 248),

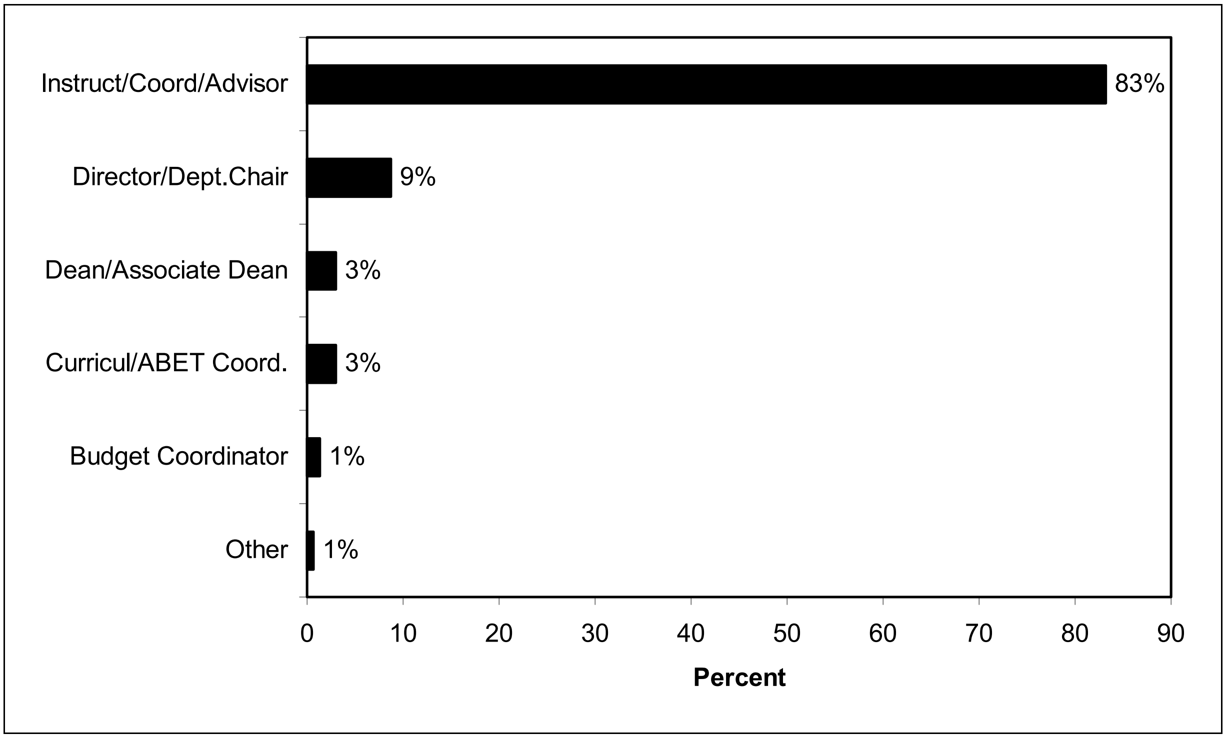

Figure 3. Percentage of Respondents by Role in Senior Capstone Design Course

(b) division director or department chair 9% (n = 26), or (c) involved in an administrative capacity as the curriculum chair/coordinator or ABET coordinator/ representative 3% (n = 9). Nine additional responses were received from the dean or associate dean, and 4 were received from project budget coordinators. Two respondents failed to complete this item.

III. Results and Discussion

The results are presented by category. Within each category, results are summarized for the entire group, depicting a national portrait. Findings are further disaggregated by discipline. Percentages are rounded to the nearest whole number. Discussion of findings follows the discipline breakouts.

The response rate for the questionnaire was reasonably high and representative. However, caution is warranted when interpreting the results for some items, particularly when disaggregated, as the responses are sometimes small in number, making generalizations tentative.

A. Information about Capstone Projects

Figure 4: Duration of Capstone Course and Project. The majority (57%, n = 171) of faculty indicated that their capstone projects are yearlong, occurring over multiple semesters or

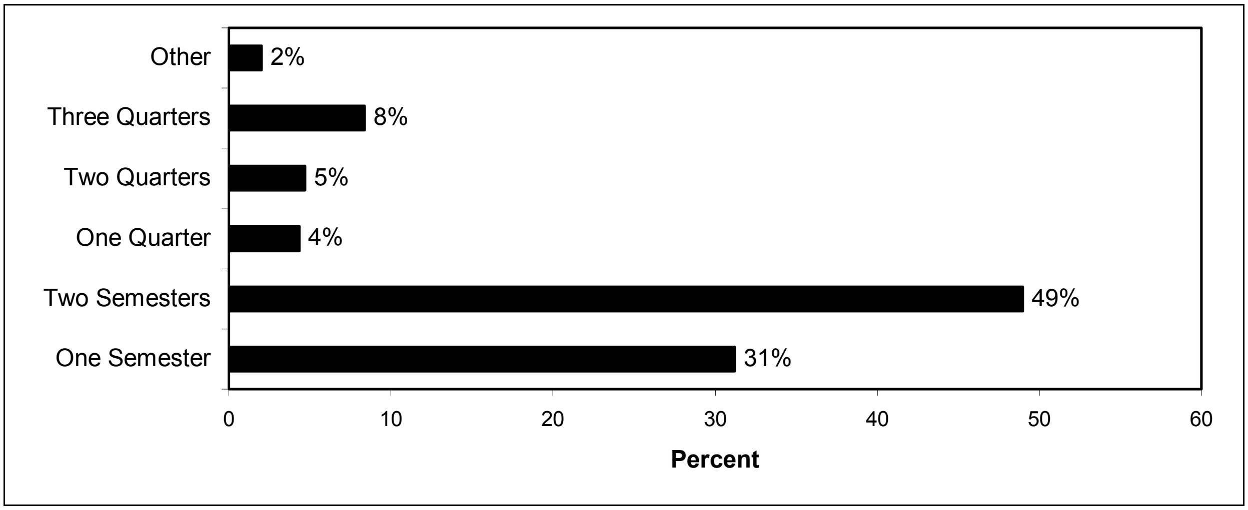

Figure 4. Duration of Capstone Course & Project

quarters. Approximately 50% of the projects occur over a two-semester period, and 8 % take place over three quarters. However, 31% of the programs are scheduled for just one semester. The smallest number of respondents is on the quarter system with 4 % having a course length of one quarter, 5% a length of two quarters and 8% having capstone course duration of three quarters.

Table 1: Capstone Duration Within Disciplines. The survey responses were also summarized by disciplines. In Table 1, frequencies and percentages are presented for attributes of capstone duration for each engineering discipline; also given are the total number of programs and percentages. This description addresses only those programs that have 10 or more responses.

Table 1 Capstone Design Project Duration Within Disciplines

Discipline (Total Responses)	One Semester	Two Semesters	One Quarter	Two Quarters	Three Quarters	Other
Agricultural/Biosystems/ Biological Systems (n=10)	2 (20%)	6 (60%)	1 (10%)		1 (10%)	
Architectural (n=2)		1 (50%)			1 (50%)	
Biomedical/Biomechanical/ Bioengineering (n=3)		3 (100%)				
Chemical/Petroleum (n=28)	13 (46%)	12 (43%)	1 (4%)	2 (7%)		
Civil/Geological/ Geophysical (n=37)	19 (51%)	13 (35%)	2 (5.4%)	1 (3%)	2 (5%)	
Computer (n=40)	7 (18%)	22 (55%)	2 (5%)	3 (8%)	4 (10%)	2 (5%)
Electrical/Microelectronic (n=47)	12 (26%)	25 (53%)		4 (9%)	4 (9%)	2 (4%)
Environmental (n=16)	7 (44%)	5(31%)	1 (6%)		3 (19%)	
Industrial/Manufacturing/ Management/Welding (n=22)	11 (50%)	7 (32%)	1(5%)	1 (5%)	1 (5%)	1 (5%)
Materials Science/Metallurgy (n=11)	4 (36%)	4 (36%)	1 (9%)		2 (18%)	
Mechanical/Aerospace/ Naval Architecture (n=73)	14 (19%)	46 (63%)	4 (6%)	2 (3%)	6 (8%)	1(1%)
Multidisciplinary/ Interdisciplinary/General (n=5)	2 (40%)	2 (40%)			1 (20%)	
Nuclear (n=3)	2 (67%)			1 (33%)		
Total (n = 298)	93 (31%)	146 (49%)	13 (4%)	14 (5%)	25 (8%)	6 (2%)

Two semester projects are characteristic of programs that typically design and/or build the projects they are working on: AgE, CmpE, EE, and ME. Programs that are more process oriented, ChemE, CivE, IE, and EnvE, tend to span only one semester.

Figure 5: Importance of Capstone Project. Ninety-two percent (92%) of the respondents attributed a great deal of importance to the capstone design course, with 59% (n = 175) reporting that it was extremely important and 33% (n = 98) reporting that it was very important. Less than 1% of respondents indicated that the capstone project was unimportant. None of the respondents self-identified as capstone instructors, coordinators or advisors reported the capstone project as unimportant.

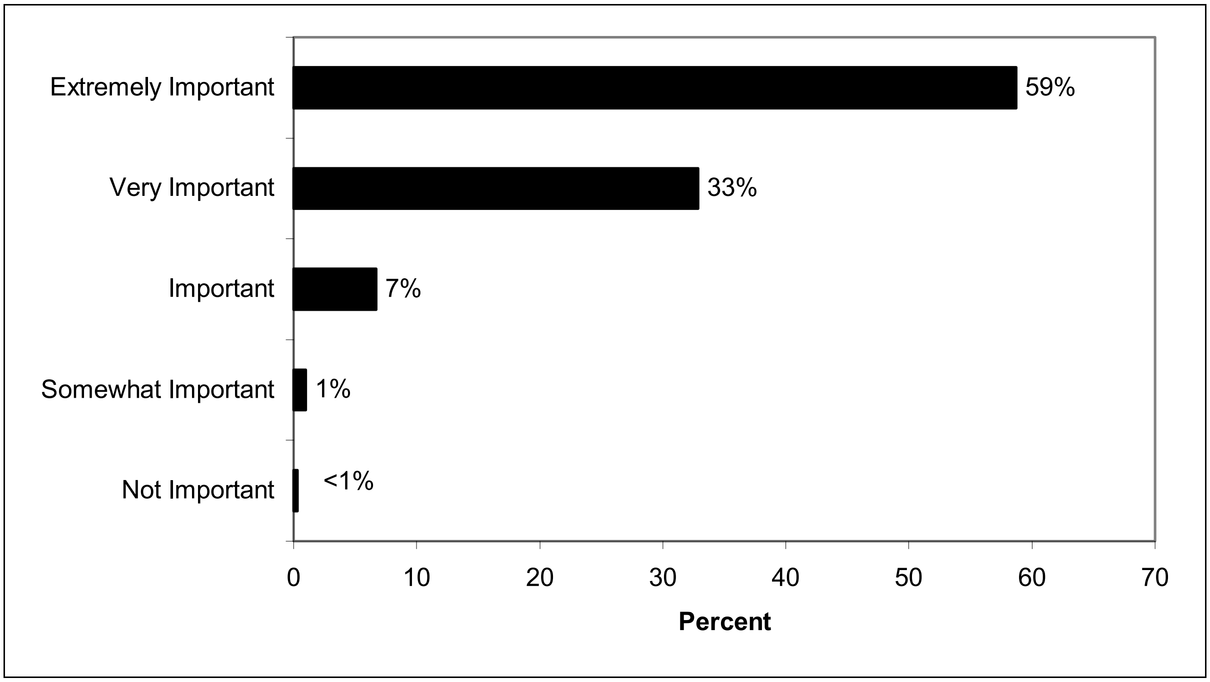

Figure 5. Magnitude of Capstone Importance

Table 2: Importance of Capstone Project Within Disciplines. This data shows that the majority of respondents (59%) indicate that the capstone experience is extremely important. All large disciplines indicated this level of importance regardless of the project being process or product oriented: ChemE, CivE, CpE, EE, EnvE, IE, and ME. The other most frequent response from each of the major disciplines shows the capstone experience as very important. These finding are consistent with findings of Todd et al. showing capstone-type courses are strongly encouraged by industry, and considered beneficial by faculty in preparing students for their chosen profession [4]. Only 1 program in CivE reported the capstone project was not important, and 3 programs in ME designated capstone as somewhat important.

Table 2 Importance of Capstone Design Project within Disciplines

	Degree of Importance [n (% within discipline)]				
Discipline (Total Responses)	Not Important	Somewhat Important	Important	Very Important	Extremely Important
Agricultural/Biosystems/ Biological Systems (n=10)				3 (30%)	7 (70%)
Architectural (n=2)				2 (100%)	
Biomedical/Biomechanical/ Bioengineering (n=3)					3 (100%)
Chemical/Petroleum (n=28)			3 (11%)	10(36%)	15 (54%)
Civil/Geological/ Geophysical (n=37)	1 (3%)		1 (3%)	14 (38%)	21 (57%)
Computer (n=40)			3 (8%)	15 (38%)	22 (55%)
Electrical/Microelectronic (n=47)			3 (6%)	17 (36%)	27 (57%)
Environmental (n=16)				7 44%)	9 (56%)
Industrial/Manufacturing/ Management/Welding (n=22)			3 (14%)	2 (10%)	17 (81%)
Materials Science/Metallurgy (n=11)			1 (9%)	7 (63%)	3 (27%)
Mechanical/Aerospace/Naval Architecture (n=73)		3 (4%)	4 (6%)	19 (26%)	47 (64%)
Multidisciplinary/ Interdisciplinary/General (n=5)			1 (20%)	2 (40%)	2 (40%)
Nuclear (n=3)			1 (33%)		2 (67%)
Total	1 (0.3%)	3 (1%)	20 (7%)	98 (33%)	175 (59%)

Figure 6: Student Organization in Capstone Projects. When asked what organization of senior design projects the responding program employed, 88% of the respondents indicated students work in teams, and 47% reported project teams comprised of multiple disciplines. Ten percent (10%) of the programs have students work on individual projects. Two percent (2%) of the departments reported the organization of the capstone projects was in a state of transition or they used a combination of individual and team projects.

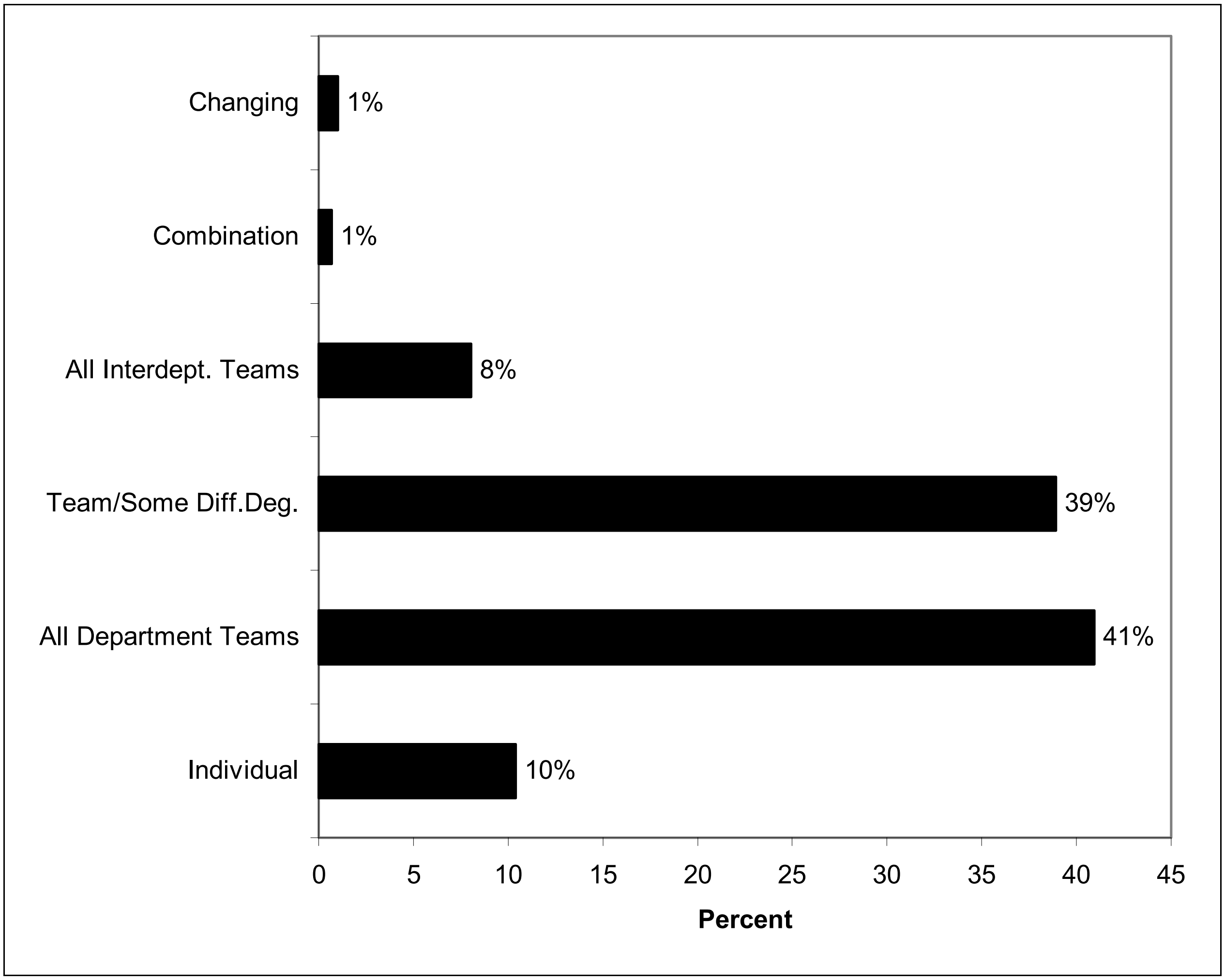

Figure 6. Type of Senior Design Project

Table 3: Type of Senior Design Project Within Disciplines**.** The majority of disciplines employ student participation in project teams. The programs most frequently using team projects with some team members from different degree programs were CpE, EE, and EnvE. Disciplines most frequently having projects with all team members in a single degree program included AgE, ChemE, CivE, and IE. Programs that predominantly use individual capstone projects were BiomE and MSE, although the sample size for these categories is small. Even these disciplines

Table 3 Student Composition of Capstone Projects Within Disciplines.

Discipline (Total Responses)	Type Project [n (% within discipline)]				
	Individual Projects	All team members in a single degree program	Some different degree program teams	Many different degree program teams	Other
Agricultural/Biosystems/Biolog.systems (n=10)		6 (60%)	4(40%)		
Architectural (n=2)		1(50%)	1(50%)		
Biomedical/Biomech./Bioengineering (n=3)	2(67%)			1(33%)	
Chemical/Petroleum (n=28)	1(4%)	23(82%)	3 (11%)		1(4%)
Civil/Geological/Geophysical (n=36)	3(8%)	21(57%)	13(35%)		
Computer (n=40)	3(8%)	13(33%)	18(45%)	5(13%)	1(3%)
Electrical/Microelectronic (n=47)	9(19%)	9(19%)	23(48%)	6(13%)	1(3%)
Environmental (n=16)	1(6%)	7(44%)	8(50%)		
Industrial/Manufact./Mgmt/Welding (n=22)	3(14%)	9 (41%)	5(23%)	5(23%)	
Materials Science/Metallurgy (n=11)	4(36%)	3 (27%)	3(27%)		1(9%)
Mechanical/Aerospace/Naval Architec.(n=73)	5(7%)	27(37%)	35(48%)	6(8%)	
Multidisciplinary/Interdisc./General (n=4)		1 (20%)	2(40%)	1(20%)	
Nuclear (n=3)		2 (67%)	1(33%)		
Total (n=298)	31(10%)	122(41%)	116(39%)	24(8%)	4(1%)

have some students working on team projects. Six (6) of the 13 disciplines also have team projects with many students from different degree programs.

Discussion. These findings suggest the following:

- Duration of Capstone Experience- Criterion 4 emphasizes product realization including detailed capstone design, prototype testing and design verification. Earlier ABET criteria encompassed only conceptual design. Consequently, a possible shift has occurred in the duration of the capstone experience to allow more comprehensive project experiences. In 1995, Todd et al. reported a large percentage of departments (45%) did both class instruction and a project in one semester[4]. Today that number with one-semester projects has diminished to 31%. The authors also stated that only 36% of responding departments had a course length of two semesters. From our survey, forty-nine percent (49%) of projects are currently two semesters in duration.

- Importance of Capstone Course- EC 2000 Criterion 4 requires an integrative project experience that encompasses a range of realistic considerations. Our survey results showing longer project durations may suggest that faculty are responding to the need for more comprehensive projects while also addressing more of the Criterion 3 outcomes. This also suggests a possible catalytic effect of the ABET requirements on enhancing students' project learning experiences..
- Composition of Teams and Projects- The organization of students working on design projects may also be changing. Our data suggests that the capstone design project offers significant potential for assessing students' abilities to work in teams, and in nearly half the cases, to work in multidisciplinary teams (as per Criterion 3d) with each team working on a different project. These percentages are higher than those reported by Todd in 1995[4], with 62% of their respondents showing all students in a given class worked on the same project, and 38% reporting 1-7 students were assigned to a team working on the same projects. The current survey found that only 10% of programs have projects done by individual students.
- Emerging Opportunities for Multidisciplinary Teams- The number of programs that emphasize a team experience for the capstone projects, and those with multi-disciplinary teams, suggest that EC 2000 accreditation criteria (e.g., outcome 3d- function on multidisciplinary teams) may be a factor in determining the student composition of teams. Although multi-disciplinary teams create additional management challenges, increasing numbers of programs are finding ways to provide students these learning experiences.

B. Development of Capstone Assessments. This section identifies the period associated with an institution's first EC 2000 Accreditation visit, and describes assessment perspectives and practices in light of specific ABET criteria.

Figure 7: EC2000 Accreditation Visit. When asked what year respondents did or would experience their first accreditation visit under Engineering Criteria 2000, 51% (n = 152) of the respondents reported their first EC 2000 accreditation visit occurred prior to 2002, while

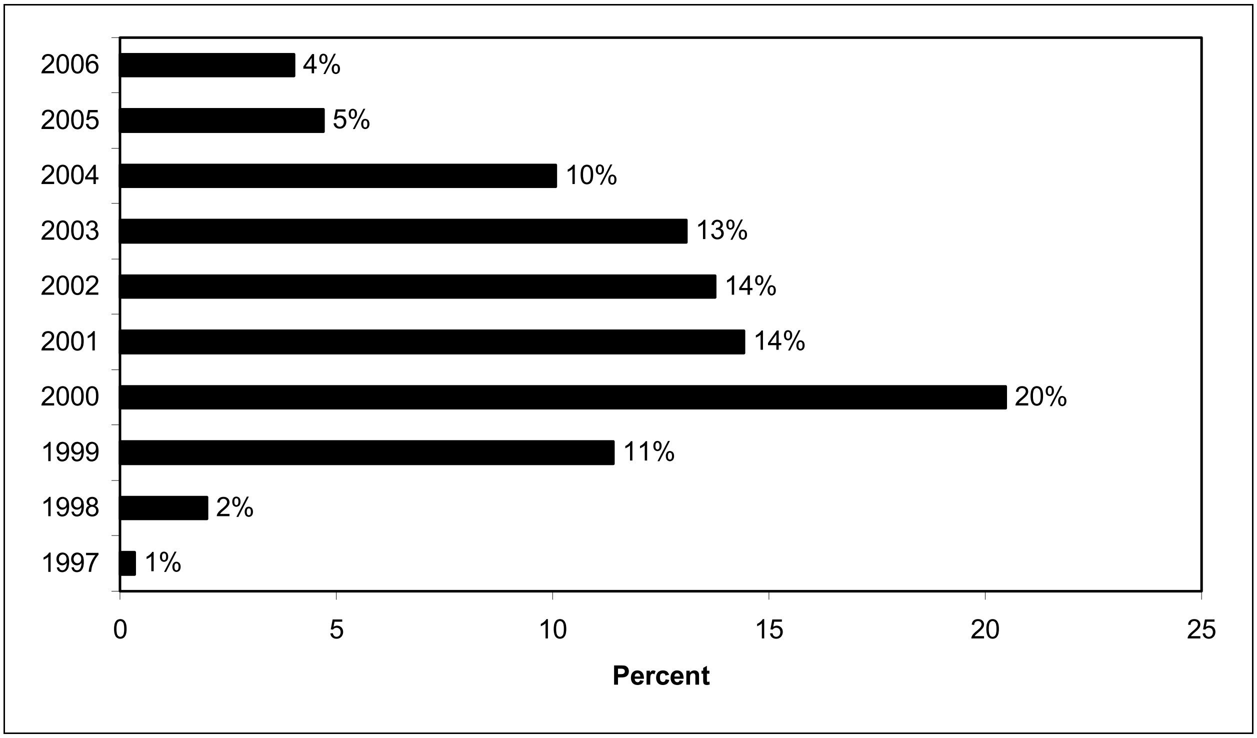

Figure 7. First Accreditation Visit Under EC 2000

roughly 49% (n = 146) indicated that it would occur some time during or after 2002.

Survey participants were also asked to identify which of Criterion 3 expectations and Criterion 4 considerations they believed were appropriate for assessment using the capstone design project, and which of these competencies they actually evaluate. Several respondents commented they were in the process of redefining capstone program outcomes and developing new instruments and rubrics to assess these outcomes.

Figure 8: Criterion 3 (a-k) Outcomes. Figure 8 shows, in order of endorsement, the Criterion 3 outcomes (and the percentage of respondents) for which they saw assessment potential

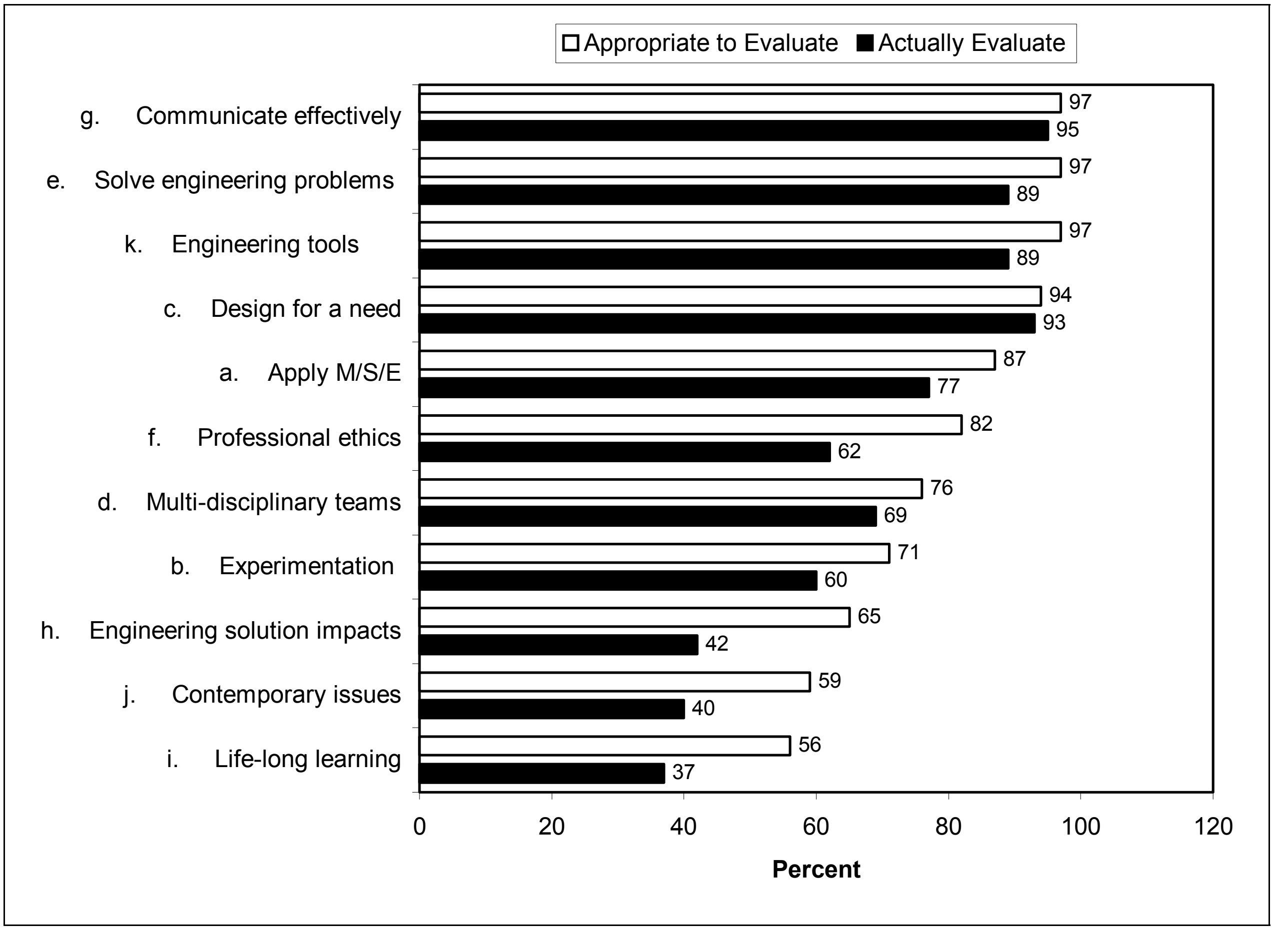

Figure 8. Role of Capstone Design Projects in Criterion 3 Outcomes Assessment

and those for which they perform assessment. For simplicity, the competencies are abbreviated. On average, eighty percent, (80%, n = 238) of the 298 respondents reported that each of Criterion 3 outcomes can be assessed within the capstone experience, but they also indicated that none of the competencies are assessed to the degree they could be. On average, seventy percent (70%, n = 209) of the respondents indicated that they actually assess each of the a-k outcomes in the context of capstone projects. Communicating effectively (outcome 3g) was reported as the most appropriate outcome for assessment in the capstone course with 97%, (n = 289) of respondents stipulating that perspective. The competency deemed the least appropriate (56%, n

= 167) for assessing in capstone projects was seeing the need for lifelong learning (outcome 3i). Other outcomes receiving high preferences for assessment were (3e) identify, formulate, and solve engineering problems, (3k) use the techniques, skills, and modern engineering tools necessary for engineering practice, and (3c) design a system, component, or process to meet desired needs. Regardless of the order of preference, faculty indicated that all of the outcomes should be assessed more extensively than is current practice.

Table 4: Criterion 3 Capstone Assessment Appropriateness Within Disciplines

Most disciplines show that all of the Criterion 3 outcomes have high potential for assessment within the capstone experience. At least 50% of the programs within each discipline acknowledge they might assess all of the a-k outcomes, except in three instances. For example, less than 50% of the groups within ChemE, CivE, and MultiDisciplinary consider outcome 3b (to design, conduct experiments, analyze and interpret data) appropriate for assessment in capstone projects. Similarly, respondents within IE, MSE, and MultiDiscipinary indicated that outcome 3i (the need for and an ability to engage in life-long learning) is suitable for assessment in capstone projects. In addition, fewer than 50% of the respondents within BiomE, and MSE believed outcome 3j (understanding contemporary issues) was proper for assessment in the senior design experience. None of the BiomE respondents considered outcome 3h (understanding the impact of engineering solutions in a global/societal context) an apt assessment target for the capstone design experience. In the same way, outcome 3b (design, conduct experiments, analyze and interpret data), and outcome 3i (recognize the need for and an ability to engage in life-long learning) were identified as inappropriate by all respondents in the nuclear discipline.

Table 4 Capstone Project Appropriateness for Criterion 3 (a-k) Outcomes Assessment (Within Disciplines)

Discipline (Total Responses)	Criterion Component [n (% within discipline)]										
	a	b	c	d	e	f	g	h	i	j	k
Agr/Biosys/ BiolSys (n=10)	10 (100)	8 (80)	9 (100)	7 (70)	10 (100)	10 (100)	10 (100)	8 (80)	7 (70)	9 (90)	10 (100)
Architectural (n=2)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	1 (50)
Biomed/Biomechan/ Bioengineering (n=3)	2 (67)	3 (100)	3 (100)	2 (67)	3 (100)	2 (67)	3 (100)		2 (67)	1 (33)	2 (67)
Chemical/ Petroleum (n=28)	27 (96)	10 (36)	27 (96)	15 (54)	28 (100)	22 (77)	27 (96)	18 (64)	16 (57)	14 (50)	28 (100)
Civil/Geological/ Geophysical (n=37)	30 (81)	18 (49)	35 (97)	27 (73)	34 (92)	28 (76)	36 (97)	26 (70)	20 (54)	24 (65)	37 (100)
Computer (n=40)	33 (83)	33 (83)	38 (95)	29 (73)	38 (95)	31 (78)	39 (98)	24 (60)	24 (60)	20 (50)	38 (95)
Electrical/Microelect. (n=48)	41 (85)	41 (85)	44 (94)	37 (77)	45 (94)	41 (85)	46 (96)	32 (67)	29 (60)	27 (56)	45 (94)
Environmental (n=16)	13 (81)	10 (63)	15 (94)	15 (94)	16 (100)	13 (81)	16 (100)	10 (63)	9 (56)	12 (75)	16 (100)
Industrial/Manuf./ Management/ Welding (n=22)	17 (77)	18 (82)	21 (96)	17 (77)	22 (100)	20 (91)	21 (96)	12 (53)	9 (41)	13 (59)	21 (96)
Materials Science/ Metallurgy (n=11)	9 (82)	8 (73)	8 (73)	6 (55)	10 (91)	8 (73)	10 (91)	6 (55)	3 (27)	4 (36)	10 (91)
Mechanical/ Aerospace/ Naval Architecture (n=73)	68 (93)	57 (78)	71 (99)	63 (86)	73 (100)	61 (84)	72 (99)	52 (71)	45 (62)	46 (63)	72 (97)
Multidisciplinary/ Interdisciplinary/ General (n=5)	4 (80)	2 (40)	5 (100)	4 (80)	5 (100)	3 (60)	5 (100)	3 (60)	2 (40)	3 (60)	5 (100)
Nuclear (n=3)	3 (100)		3 (100)	2 (67)	3 (100)	2 (67)	3 (100)	2 (67)		2 (67)	3 (100)
Total % of Total (n=298)	259 (87)	210 (71)	281 (96)	226 (76)	289 (97)	243 (82)	290 (97)	195 (65)	168 (56)	177 (59)	288 (97)

Table 5: Actual Evaluation of Criterion 3 (a-k) Outcomes within Disciplines**.**

In general, all of the disciplines assess fewer outcomes using the capstone project than they believe is possible. In addition, when comparing the percent differences between potential versus actual assessment of Criterion 3 outcomes, on average, the major programs assess approximately 10% fewer outcomes than they believe is possible: ChemE (14%), CivE (9%), CpE (10%), EE (10%), EnvE (13%), IE (18%), MSE (6%) and ME (13%). Fewer than 50% of

Table 5 Capstone Project Actual Evaluation of Criterion 3 (a-k) Outcomes (Within Disciplines)

Discipline (Total Responses)	Criterion [n (% within discipline)]										
	a	b	c	d	e	f	g	h	i	j	k
Agri./Biosys./ Biolog.Sys. (n=10)	8 (80)	7 (70)	10 (100)	7 (70)	8 (80)	10 (100)	10 (100)	7 (70)	4 (40)	6 (60)	10 (100)
Architectural (n=2)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	1 (50)	2 (100)	2 (100)	1 (50)	2 (100)	2 (100)
Biomed./Biomech./ Bioengr. (n=3)	3 (100)	2 (67)	3 (100)	2 (67)	3 (100)	1 (33)	3 (100)				2 (67)
Chemical/ Petroleum (n=28)	24 (86)	8 (29)	26 (93)	12 (43)	25 (89)	13 (46)	27 (96)	9 (32)	8 (29)	7 (25)	25 (89)
Civil/Geol./ Geophysical (n=37)	27 (73)	15 (41)	35 (95)	25 (68)	32 (87)	27 (73)	36 (97)	17 (46)	13 (35)	17 (46)	35 (95)
Computer (n=40)	26 (67)	30 (75)	38 (95)	29 (73)	38 (95)	25 (63)	38 (95)	15 (38)	16 (40)	13 (33)	34 (85)
Electrical/ Microelec. (n=48)	36 (77)	37 (79)	45 (96)	35 (75)	45 (96)	29 (62)	46 (98)	21 (45)	22 (47)	19 (40)	40 (85)
Environmental (n=16)	12 (75)	8 (50)	14 (88)	13 (81)	13 (81)	9 (56)	16 (100)	6 (38)	7 (44)	8 (50)	16 (100)
Indust./Manuf./ Mgmt/Weld.(n=22)	16 (73)	14 (64)	19 (86)	15 (68)	19 (86)	13 (59)	20 (91)	7 (32)	5 (23)	7 (32)	16 (73)
Materials Sci./ Metal. (n=11)	8 (73)	6 (55)	8 (73)	6 (55)	10 (91)	6 (55)	9 (82)	5 (46)	3 (27)	4 (36)	10 (91)
Mechan./Aero./ Naval Arch (n=73)	60 (82)	48 (66)	69 (95)	56 (77)	64 (89)	47 (64)	68 (93)	33 (45)	32 (44)	34 (47)	67 (92)
Multidisc./Interdisc./ General (n=5)	3 (60)	2 (40)	5 (100)	2 (40)	5 (100)	3 (60)	5 (100)			1 (20)	5 (100)
Nuclear (n=3)	3 (100)		3 (100)	2 (67)	2 (67)	2 (67)	3 (100)	2 (67)		2 (67)	3 (100)
Total % of Total (298)	228 (77)	179 (60)	277 (93)	206 (69)	266 (90)	186 (63)	283 (95)	124 (42)	111 (37)	120 (40)	265 (89)

all respondents for the major disciplines (i.e., ChemE, CivE, CpE, EE, EnvE, IE, MSE, and ME) assess outcomes 3h, 3i, and 3j to the extent they believe possible. None of the respondents for BiomE assess any of these three outcomes in the capstone project, nor do any of the MultiE respondents assess 3h or 3i.

Figure 9: Criterion 4. Figure 9 shows, in order of priority, the Criterion 4 prescribed design constraint considerations and the number and percentage of respondents with respect to assessment suitability and practice. Compared to Criterion 3 outcomes, fewer respondents reported Criterion 4 design constraint considerations appropriate for assessment in the capstone project. When considering the outcomes individually, on average, 50% of the respondents

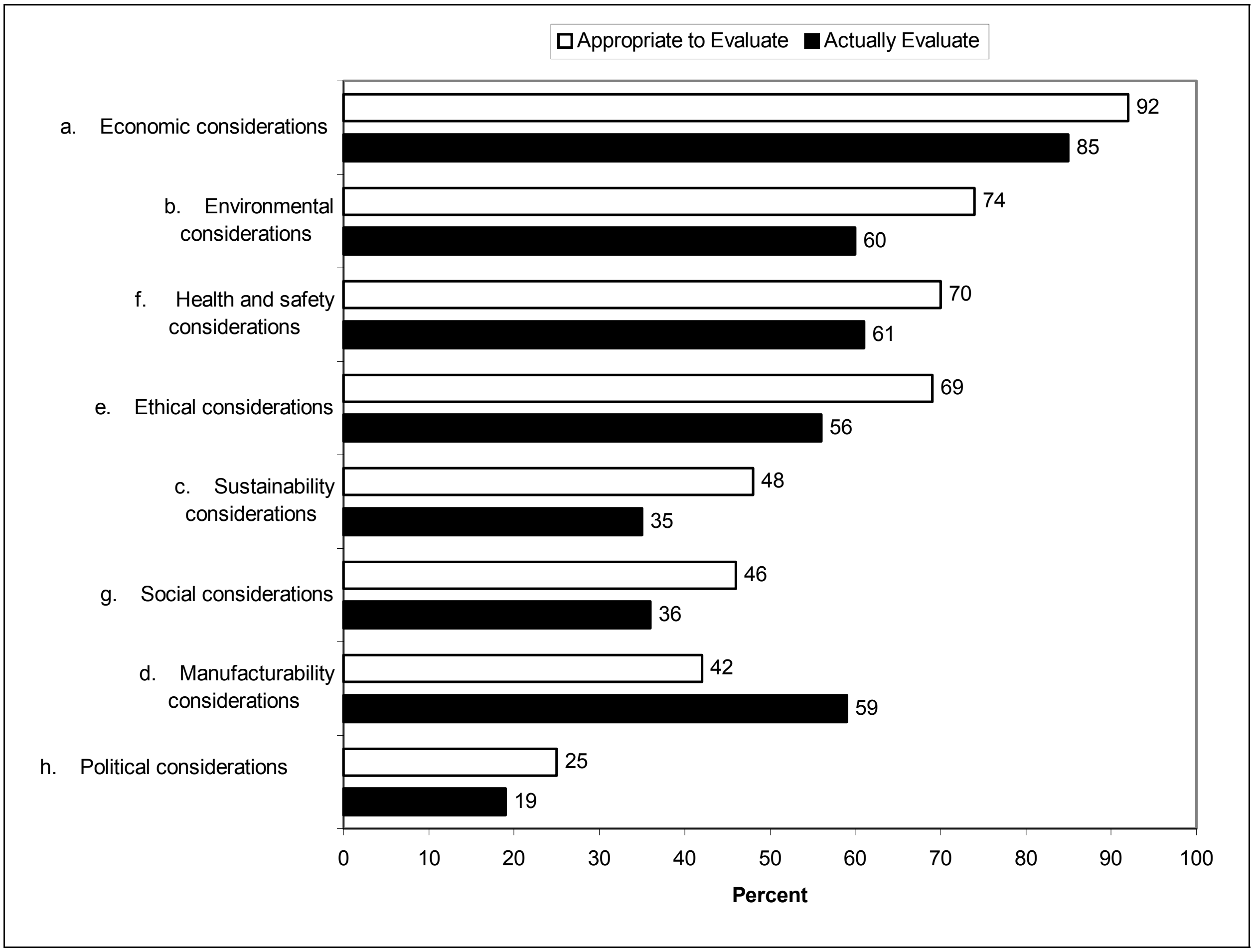

Figure 9. Role of Capstone Design Projects in Criterion 4 Outcomes Assessment

indicated a specific constraint appropriate for assessment in their capstone projects. Ninety-two percent (92%) believed economic considerations were appropriate for assessment. Political considerations were reported as the least suitable for assessment in the capstone project. More than 70% of the respondents, in order of preference, noted economic, environmental, health and safety, and ethical considerations as being appropriate for assessment in capstone projects.

However, respondents reported that none of those items are currently being assessed to the level possible. Fewer than half of the participants reported sustainability, social considerations, manufacturability, or political considerations were suitable for evaluation in capstone projects. Respondents reported all but one of the Criterion 4 considerations were not being assessed as much as they believed possible. However, more programs (59%) assess manufacturability considerations in the capstone project than deemed this assessment appropriate (42%).

Table 6: Capstone Project Appropriateness for Criterion 4 Assessment Within Disciplines.

Disciplines with 11 or fewer responses are listed in both Tables 6 and 7 for information, but are not discussed in detail due to the small number of responses. Overall, components of Criterion 4 were less likely to be identified as capstone assessment targets than those of Criterion 3. On average, less than 50% of the respondents for each discipline selected sustainability (constraint 4c), manufacturability (constraint 4d), social considerations (constraint 4g), and political considerations (constraint 4h) as being appropriate for assessment in these projects, while more than 50% of each discipline agreed that economic, environmental, ethical, safety and health considerations were viable for assessment in capstone projects.

When considering programs with 16 or more responses, the programs for which highest percentages identified a constraint suitable for assessment were: sustainability considerations, EnvE (56%); manufacturability considerations, IE (64%); social considerations, CivE (65%); and political considerations, CivE (30%). Chemical Engineering programs reported the design constraints least appropriate for capstone assessment included: sustainability considerations, manufacturability considerations, social considerations, and political considerations.

Table 6 Capstone Appropriateness for Criterion 4 Assessment Within Disciplines

Discipline (Total Responses)	Criterion [n (% within discipline)]							
	a	b	c	d	e	f	g	h
Agricultural/Biosystems/ Biological Systems (n=10)	10 (100)	9 (90)	8 (80)	4 (40)	10 (100)	8 (80)	7 (70)	4 (40)
Architectural (n=2)	2 (100)	2 (100)	1 (50)		1 (50)	2 (100)	2 (100)	1 (50)
Biomedical/Biomechanical /Bioengineering (n=3)	2 (67)	2 (67)	2 (67)		2 (67)	2 (67)		
Chemical/Petroleum (n=28)	28 (100)	26 (93)	10 (36)	6 (21)	17 (67)	24 (86)	6 (21)	3 (11)
Civil/Geological/ Geophysical (n=37)	37 (100)	36 (97)	19 (51)	9 (24)	26 (70)	25 (68)	24 (65)	11 (30)
Computer (n=40)	32 (80)	21 (53)	18 (45)	16 (40)	27 (68)	24 (60)	14 (35)	10 (25)
Electrical/ Microelectronic (n=48)	40 (83)	26 (54)	18 (38)	20 (42)	32 (67)	32 (67)	20 (42)	12 (25)
Environmental (n=16)	16 (100)	15 (94)	9 (56)	4 (25)	14 (88)	10 (63)	10 (63)	4 (25)
Industrial/Manufacturing/ Management/Welding (n=22)	18 (82)	11 (50)	9 (41)	14 (64)	14 (64)	14 (64)	7 (32)	4 (18)
Materials Science/ Metallurgy (n=11)	9 (82)	8 (73)	1 (9)	8 (73)	6 (55)	8 (73)	4 (36)	
Mechanical/ Aerospace/Naval Architecture (n=73)	71 (97)	56 (77)	44 (60)	38 (52)	52 (71)	56 (77)	38 (52)	21 (29)
Multidisciplinary /Interdisciplinary/General (n=5)	5 (100)	4 (80)	2 (40)	4 (80)	3 (60)	2 (40)	3 (60)	2 (40)
Nuclear (n=3)	3 (100)	3 (100)	1 (33)	2 (67)	2 (67)	2 (67)	1 (33)	1 (33)
Total % of Total (298)	273 (92)	219 (74)	142 (48)	125 (42)	206 (69)	209 (70)	136 (46)	73 (25)

Table 7: Actual Assessment of Criterion 4 Within Disciplines. When comparing the percent differences between possible versus actual assessment of Criterion 4 (a-g) considerations, on average, the major programs assess approximately 10% fewer considerations than are possible: ChemE (10%), CivE (8%), CpE (13%), EE (7%), EnvE (8%), IE (7%), and ME (14%). It is interesting to note that all of the major disciplines (16 or more responses), on average, assess

manufacturability (consideration d) in the capstone project 15% more often than they thought it fitting. None of the respondents for MSE assess outcome (4h) political considerations.

Table 7 Capstone Actual Evaluation of Criterion 4 Within Disciplines

Discipline (Total Responses)	Criterion [n (% within discipline)]							
	a	b	c	d	e	f	g	h
Agricultural/Biosystems/ Biological Systems (n=10)	10 (100)	8 (80)	6 (60)	6 (60)	10 (100)	8 (80)	7 (70)	2 (20)
Architectural (n=2)	2 (100)	2 (100)	1 (50)	1 (50)	1 (50)	2 (100)	2 (100)	1 (50)
Biomedical/Biomechanical /Bioengineering (n=3)	2 (67)	1 (33)	2 (67)	2 (67)	2 (67)	2 (67)	1 (33)	1 (33)
Chemical/Petroleum (n=28)	27 (96)	22 (79)	7 (25)	9 (32)	12 (43)	21 (75)	4 (14)	2 (7)
Civil/Geological/ Geophysical (n=37)	34 (92)	30 (81)	16 (43)	12 (32)	25 (68)	23 (62)	18 (49)	10 (27)
Computer (n=40)	28 (70)	15 (38)	11 (28)	24 (60)	19 (48)	18 (45)	10 (25)	6 (15)
Electrical/ Microelectronic (n=48)	37 (79)	21 (45)	12 (26)	31 (66)	24 (51)	27 (57)	17 (36)	9 (19)
Environmental (n=16)	16 (100)	15 (94)	6 (38)	4 (25)	11 (69)	10 (63)	7 (44)	4 (25)
Industrial/Manufacturing/ Management/Welding (n=22)	17 (77)	9 (41)	7 (32)	16 (73)	12 (55)	12 (55)	5 (23)	3 (14)
Materials Science/ Metallurgy (n=11)	10 (91)	7 (64)	1 (9)	8 (73)	5 (46)	7 (64)	4 (36)	
Mechanical/ Aerospace/Naval Architecture (n=73)	62 (85)	41 (56)	33 (45)	55 (75)	41 (56)	47 (64)	28 (38)	16 (22)
Multidisciplinary /Interdisciplinary/General (n=5)	5 (100)	4 (80)	2 (40)	5 (100)	3 (60)	2 (40)	2 (40)	1 (20)
Nuclear (n=3)	3 (100)	3 (100)	1 (33)	2 (67)	1 (33)	2 (67)	1 (33)	1 (33)
Total % of Total (298)	253 (85)	178 (60)	105 (35)	175 (59)	166 (56)	181 (61)	106 (36)	56 (19)

Results were further disaggregated by time of ABET visit. Comparisons were made between programs receiving EC 2000 accreditation visits before 2002 and those receiving visits during or after 2002. The results showed negligible differences between these two groups for both Criterion 3 outcomes and Criterion 4 considerations.

Results from this section of items suggest the following implications:

- Appropriateness of Capstone as Focus for Outcomes Assessment- The majority of faculty believe all Criterion 3 (a-k) outcomes are appropriate to evaluate in the capstone design course; approximately one half of these outcomes (b, h, j, and i) are assessed significantly less than believed possible. The disparity between actual and potential assessment of outcomes may reflect early stages of modification. These findings suggest a lack of preparedness among faculty to effectively develop and manage assessments of some of these outcomes. Many respondents commented on the survey that they were in the process of revising, or planning an extensive revision of, their senior design program outcomes and associated assessment instruments.
- Confusion Surrounding Criterion 4- Fifty percent (50%) of the design constraint considerations (c, g, d, and h) were reported as being appropriate for assessment in capstone design. Whereas many of Criterion 3 outcomes are addressed in the first three years of the curriculum, Criterion 4 design constraint considerations do not usually occur prior to the senior capstone experience. Consequently, capstone course faculty encountering these new Criterion 4 constraints for the first time may find these difficult to integrate adequately into the capstone experience, creating challenges also for faculty seeking to determine if they have been addressed adequately. Note that criterion 3 expectations are referred to as outcomes, and are stated with some detail. This detail provides a solid basis to fashion assessment of outcomes. On the other hand, criterion 4 are design constraint considerations to be included in capstone project experiences. These considerations are stated in an open-ended fashion that allows flexibility in their application depending on the design project and discipline. The flexibility, however,

poses unique assessment challenges for faculty. As a precursor to assessment, faculty must develop clear understanding of relevant considerations, how these considerations are embodied within a particular design project, and how best to communicate this to students.

- Need for Collaboration in Capstone Assessment- The differences among responses from one discipline to another indicates a possible need for national collaboration within each or a cluster of disciplines. Apparently, faculty across disciplines and institutions are unilaterally approaching the implementation of the new accreditation criteria. Collaboration will enable development of assessment instruments that are reliable and valid for a given discipline. Where responses do not differ markedly, common assessments may be suitable.

C. Collaboration Interest

The survey identified 146 engineering professors representing 192 programs from 97 universities indicating their interest in collaborating in the development of high quality end-of-program assessment instruments based on capstone design projects. (Note: The reason for more programs than professors in this summary is that some professors represented more than one program, e.g., Civil/Environmental or Computer/Electrical engineering at their schools, while other schools have different individuals responding for these disciplines.) The breakdown of all respondents wishing to collaborate by region and institution includes North East (18 institutions), South (30 institutions), North Central (27 institutions), and West (22 institutions). The strong interest among faculty across all programs and institutions may also signal some uncertainty about how best to meet EC 2000 accreditation requirements and to obtain reliable student achievement data for guiding curricular improvements.

IV. Summary and Conclusions

This paper described the results of a nationwide survey concerning the assessment of ABET EC 2000 Criteria 3 and 4 expectations within the context of a comprehensive design project. A majority of respondents felt that all competencies cited by Criterion 3 and half of the design constraint considerations cited by Criterion 4 of EC 2000 were appropriate for evaluation in the capstone design course. Respondents also indicated that those competencies suitable for assessment should be evaluated more extensively than is current practice. Criterion 3 outcomes appear to have sufficient specificity that enables faculty comprehension of ABET's expectations. Assessment of criterion 3 outcomes is fairly straightforward. In contrast, the lack of specificity in Criterion 4 design constraint considerations makes assessment of them considerably difficult. Consequently, it is recommended that ABET consider developing clearer definitions for Criterion 4 expectations. For example, the accrediting agency could quantify the term "most" in its description of Criterion 4, and prioritize which of the considerations economic, environmental, sustainability, manufacturability, ethical, health and safety, social, or political are of paramount importance.

Further, the implementation of the new accreditation criteria that emphasizes outcome-based assessment has perhaps heightened faculty awareness of the importance of the capstone experience, and has done so across the nation. The study documented a nationwide interest among capstone design faculty to collaborate on the development of capstone assessment instruments.

However, the wide variation among disciplines concerning preferred and actual assessment of Criterion 3 (a-k) outcomes and Criterion 4 design constraint considerations possibly indicates faculty uncertainty with the new accreditation expectations and how best to revise their programs accordingly. If all 274 accredited programs are approaching the new criteria in such a mixed fashion, this may also indicate an inefficient use of academic engineering resources in the United States. One possible strategy is national collaboration in defining capstone program outcomes and in developing reliable, valid, and versatile capstone assessment instruments.

This survey indicates a nationwide interest among capstone design faculty to collaborate on the development of assessment instruments. To ensure optimal collaboration and sharing of assessment processes and tools, a national data base repository could be established to minimize "rework" across institutions and maximize efficiency. As an example, the nuclear utility industry through its accrediting agency, the Institute of Nuclear Power Operations (INPO), developed such a repository shortly after the March 1979 accident at Three Mile Island. William S. Lee, then CEO of Duke Power Company and founder of INPO believed sharing of information between nuclear plants was necessary for the survival of the industry. Given the need to enhance undergraduate engineering experiences across the country and the limitations of tight university budgets, sharing accreditation related information and practices widely may be in our national interest for ensuring the professional development of a quality engineering workforce.

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