STUDENT AND FACULTY PERCEPTIONS OF CAPSTONE PURPOSES: WHAT CAN ENGINEERING LEARN FROM OTHER DISCIPLINES?

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Abstract – *Capstone Experiences (CE) are meant to integrate and culminate the student experience. The most common CE in the Canadian and American engineering curriculums is the final year design course, but other disciplines also have capstone experiences.*

This paper presents initial results from a multi-institutional, multi-national survey of faculty and student perceptions of capstone experiences. Here, we investigate three criteria (Values, Skills/competencies, Attitudes) and discuss differences and similarities among the disciplines and between engineering students and faculty.

There is good alignment between engineering faculty and students, but values such as openness and compassion are selected at (comparatively) lower rates by engineering faculty and students than by other disciplines. These findings provide an opportunity for engineering educators to reflect on the intentions of their CE; e.g., are these results an intentional outcome of engineering capstones, or an oversight on the part of engineering educators?

Keywords: Capstone, Design, Outcomes, Values, Skills and Competencies

1. INTRODUCTION

Accredited engineering programs across Canada and the United states require all students to engage in a capstone design experience. These experiential learning opportunities allow students to engage in a realistic engineering design process. Due to their culminating nature, capstone design courses provide a rich source of data for graduate attributes for which data is often sparse and/or low quality (e.g., ethics, lifelong learning, etc.).

Other disciplines also provide capstone experiences for their students. Some capstones (e.g., engineering design courses) focus on the skills and knowledge gained during the program, while others (e.g., [1]) are concerned primarily with the individual's personal growth and career plans. Additionally, some capstones seek to integrate multiple disciplines (e.g., [2]), while others are discipline focused, such as an individual fourth year thesis (e.g., [3]).

In all cases, capstone experiences are meant to provide a culminating and transitional experience ([4] and [5]). A

wealth of research in the US (e.g., [6], [7]) has explored the intent behind these experiences. However, while cross-disciplinary research on CE exists (e.g., [8] integrated results from the first four years of the Senior Year Experience National Conference), [9] observes that "there is a need for additional multi-discipline, multi-institutional studies to more fully explore the variation of capstones…" (see also [10]). In addition, there is little exploration of the alignment between how students and faculty view the intent and result of these experiences [11].

In this paper, we focus on three broad Learning Outcome categories, which were defined for participants as follows:

> **Values:** your principles or standards of behavior; your judgment of what is important in life.

> **Skills/Competencies:** the broad range of abilities necessary to perform well in university, employment or society, with results of acceptable quality.

> **Attitudes:** your way of thinking or feeling about someone or something, typically one that is reflected in [your] behavior.

1.1. Background

Existing research has explored methods of describing the overarching goals of a capstone experience, including the use of surveys ([11], [12]) document analyses [9], and expert panels [13] to describe programmatic objectives and goals, but none of these studies investigate whether these outcomes are affected (or perceived to be affected) in students who actually take a capstone course.

The Canadian and American engineering CE is required for accreditation and must include a culminating design experience [14], [15]. In [16], the authors surveyed 25 engineering capstone courses across Canada and found that all involved delivery through a group project, which was then assessed via a written report, an oral presentation, and in some cases a working prototype. In most cases, the projects were found to be open-ended, and the problems had been generated from either the faculty advisor's research program, an industry partner, or in some cases the problem had been student generated. As a result, the study

noted that the design projects were of "diminished scope", in most cases lacking the initial stages of needs analysis and problem definition. Implicitly, this means that the students in those courses do not have the opportunity to develop related skills, values, or attitudes.

Finally, Henscheid et al. [6] investigated syllabi from over 500 public and private U.S. institutions and found that nearly three-quarters were influenced by disciplinary conventions and/departmental policies. This influence may extend to student and faculty perceptions of purposes of capstone.

1.2. Research goals

This paper is part of a larger research project that seeks to investigate student and faculty perceptions of the purposes of capstone experiences, including comparisons across discipline, country, and institution. In this paper, we narrow our focus to the differences between engineering and other disciplines and between engineering faculty and engineering students with the dual goals of better understanding the impact of engineering capstones on students and encouraging critical reflection on the desired outcomes of engineering capstone design courses.

2. METHODS AND MATERIALS

All data presented in this paper was obtained via two REB approved surveys (faculty and student) run over two years. Ethics approval was obtained at all participating institutions.

2.1. Survey

The survey was developed during year one of the Elon Center for Engaged Learning's Capstone Experiences Seminar [17]. At the seminar, there were 25 attendees from four countries, comprising a broad cross-section of disciplinary backgrounds. All participants had experience with teaching capstone and many participants had deep experience with pedagogical research and survey design.

The researchers leveraged the participants' expertise to develop the three categories and the item lists. A literature review (e.g., see [13] and the references therein) was also conducted to generate initial lists, which were then simplified through a process of identifying synonyms and/or identifying items of particular interest to some disciplines (e.g., an engineering participant insisted on including *Professionalism*, while a theology participant insisted on including *Spiritual*).

2.2. Participants

Participants were drawn from four universities in three different countries (Table 2). Individuals were invited to participate using an anonymous link distributed via email, either through list-serves or through course-based announcements. Faculty participants were excluded if they had never taught a capstone and student participants were excluded if they had never taken a capstone.

Participants were asked to select their discipline from a pre-defined list. During analysis, these disciplines were categorized (Table 1):

Engineering: Engineering **STEM, Non-engineering**: Physical Science, Mathematics, Medicine, Technology, Environmental Studies

Social Science: Psychology, Education, Geography, Social Science, Economics, Political Science

Humanities: Languages, Arts, History, Literature, Philosophy

Table 1: Participant numbers by discipline

Discipline		Faculty (n=67)	Student (n=124)
STEM	Non-Engineering	9	50
	Engineering	10	17
Social Science		25	32
Humanities		23	25

3. RESULTS

Here, we present two sets of results: (1) Participant ranking of the importance of the three categories and (2) Participant selection of items from each category that are affected by their capstone. To better represent differences and similarities among the disciplines, all results have been normalized to the number of respondents in each discipline.

Table 2: Participating institutional details

Institution	Approx. UG population	Type	Public/Private	Country
University of Guelph (UG)	25,000	Comprehensive research	Public	Canada
Boston College (BC)	9,000	Liberal arts	Private	USA
University of West England – Bristol (UWE)	22,000	Comprehensive teaching	Public	UK
Penn State Harrisburg (PSU)	4,000	Comprehensive research	Public	USA

3.1. Categories

Participants were asked to "rank the three categories [Values, Skills and Competencies, Attitudes] from most important to least important in the context of your capstone." (Figure 1 and Figure 2). Students in all disciplines except engineering tended to select *values* as most important and *skills/competencies* as least important. Non-engineering faculty were more varied in their responses, particularly Social Science and non-engineering STEM who selected *skills/competencies* and *values* as most and least important at similar rates. These results are strikingly different for engineers, who overwhelmingly choose *skills/competencies* as most important. engineering students tended to select *values* as least important, while engineering faculty split between *values* and *attitudes* as least important.

3.2. Item descriptors

For each of the three categories, participants selected their top five descriptors from pre-populated lists; for example, in *values*, faculty participants were asked "What values do you think are affected by the capstone?" The option to select 'none' was included. Table 3 shows the collected results, with heat maps for each subsection (e.g., student values).

Notable **disciplinary** differences between **students** (Table 4) include

Values: Engineering selects *Thoughtfulness, Compassion,* and *Openness* at much lower rates (comparatively) while humanities selects *Professionalism* at much lower rates

Skills: Engineering selects *Problem solving* at a much higher rate (interestingly, all groups select *Critical thinking* at high rates, which begs the questions of what the perceived difference is), STEM overall selects *Communication – written* at higher rates, and engineering selects *Communication – Verbal, Lifelong learning,* and *Interpersonal skills* at lower rates (note that all groups select *teamwork* at similar rates, again raising questions of what differentiates *teamwork* from *interpersonal skills*). Finally, social science students select *Research* at lower rates.

Attitudes: Engineering selects *Professional* at higher levels and *Concerned for the well being of others* at lower rates. Interestingly, engineering and social sciences select *Self aware* at similar (lower) rates, while humanities and non-engineering STEM select it at similar (higher) rates. Humanities selects *Motivated/Enthusiastic* at much lower rates.
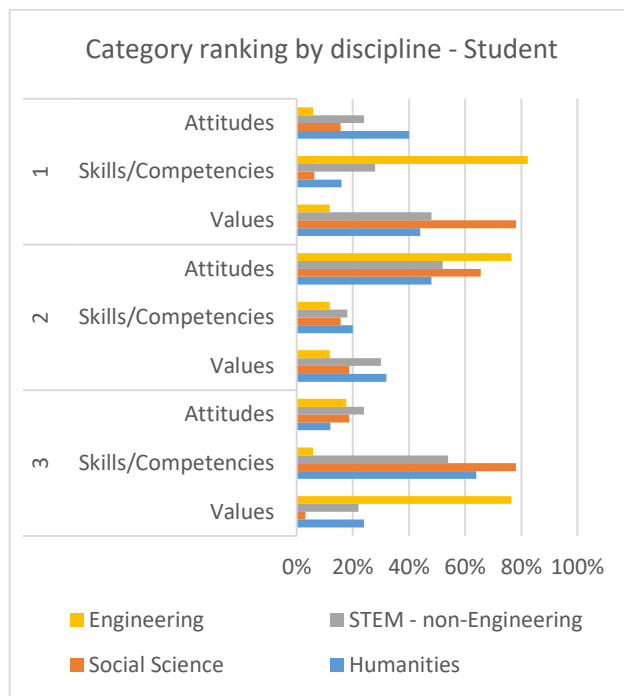

Figure 1: Student category ranking from most important (1) to least important (3). Split is shown according to discipline
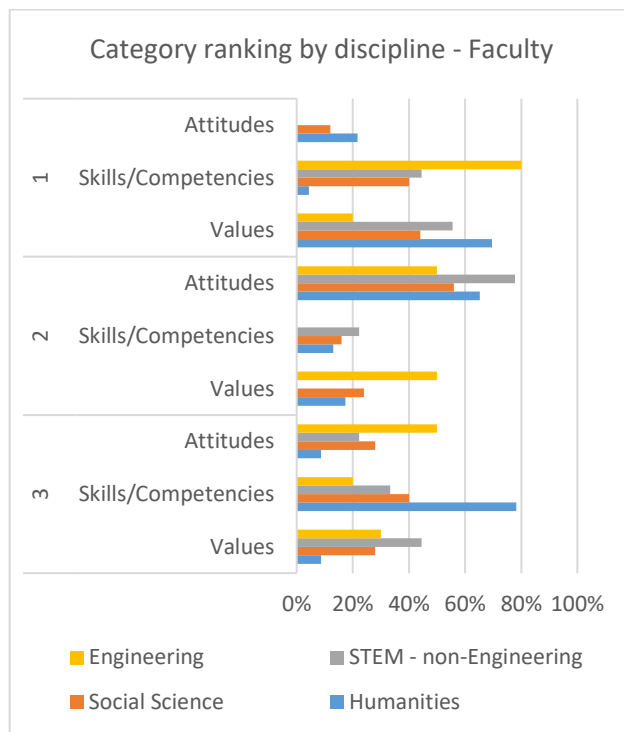

Figure 2: Faculty category ranking from most important (1) to least important (3). Split is shown according to discipline

Table 3: Heat maps for all terms organized by category and by faculty vs student

| | | Students | | | | Faculty | | | | |
		Humanities	Social Science	STEM - non engineering	Engineering	Humanities	Social Science	STEM - non engineering	Engineering	
Values	Responsibility	32%	53%	64%	65%	30%	56%	78%	100%	Responsibility
	Integrity	24%	25%	34%	24%	39%	60%	44%	100%	Integrity
	Professionalism	28%	44%	52%	59%	0%	44%	56%	90%	Professionalism
	Career orientation	52%	53%	42%	59%	17%	40%	56%	60%	Career orientation
	Ethical sensitivity	20%	22%	22%	47%	43%	48%	33%	50%	Ethical sensitivity
	Thoughtfulness	60%	50%	42%	24%	61%	52%	56%	40%	Thoughtfulness
	Openness	68%	41%	34%	12%	52%	40%	22%	10%	Openness
	Other	20%	16%	10%	0%	39%	24%	22%	10%	Other
	Empathy	32%	31%	38%	18%	43%	40%	11%	10%	Empathy
	Inter-cultural sensitivity	16%	19%	22%	12%	52%	20%	67%	0%	Inter-cultural sensitivity
	Citizenship	8%	13%	12%	6%	48%	12%	33%	0%	Citizenship
	Compassion	32%	44%	30%	6%	43%	32%	22%	0%	Compassion
	None	0%	0%	0%	12%	0%	0%	0%	0%	None
Skills	Communication - written	24%	16%	46%	41%	61%	60%	100%	100%	Communication - written
	Critical thinking	68%	56%	50%	76%	78%	92%	67%	80%	Critical thinking
	Teamwork	24%	31%	26%	35%	35%	20%	22%	70%	Teamwork
	Problem solving	8%	13%	14%	59%	13%	24%	11%	70%	Problem solving
	Personal/org. mgt.	48%	72%	62%	41%	17%	36%	56%	40%	Personal/org. mgt.
	Communication - verbal	28%	41%	38%	18%	57%	56%	22%	40%	Communication - verbal
	Lifelong learning	68%	66%	58%	29%	52%	52%	44%	30%	Lifelong learning
	Research	32%	16%	34%	47%	9%	40%	44%	30%	Research
	Critical reading	20%	13%	28%	18%	26%	32%	44%	20%	Critical reading
	Information literacy	16%	9%	6%	29%	13%	28%	44%	20%	Information literacy
	None	0%	0%	2%	0%	9%	36%	44%	20%	None
	Other	8%	0%	6%	18%	30%	16%	22%	0%	Other
	Interpersonal skills	52%	69%	48%	24%	57%	24%	11%	0%	Interpersonal skills
Attitudes	Professional	28%	31%	26%	47%	9%	24%	33%	90%	Professional
	Responsible	36%	28%	52%	41%	13%	28%	56%	80%	Responsible
	Independent/Self-confident	48%	38%	52%	35%	30%	60%	78%	50%	Independent/Self-confident
	Open-minded/tolerant	36%	41%	40%	41%	39%	40%	44%	50%	Open-minded/tolerant
	Societally aware	32%	28%	14%	24%	52%	56%	44%	40%	Societally aware
	Resilient/Determined	28%	25%	16%	12%	39%	24%	33%	40%	Resilient/Determined
	Curious	48%	47%	42%	41%	13%	52%	33%	30%	Curious
	Honest	16%	16%	12%	6%	26%	28%	22%	30%	Honest
	Motivated/Enthusiastic	28%	50%	58%	65%	39%	44%	0%	30%	Motivated/Enthusiastic
	Insightful	40%	28%	34%	41%	48%	20%	44%	10%	Insightful
	Conc. well-being of others	28%	41%	34%	12%	22%	4%	22%	10%	Conc. well-being of others
	Self aware	72%	50%	70%	35%	65%	20%	22%	0%	Self aware
	None	0%	0%	0%	12%	9%	4%	11%	0%	None
	Spiritual	20%	19%	14%	6%	52%	32%	11%	0%	Spiritual

Table 4: Differences between disciplines in the student group - identified via standard deviation

	Humanities	Social Science	STEM - non engineering	Engineering	Std. Dev.
Problem solving	8%	13%	14%	59%	0.24
Motivated/ Enthusiastic	28%	50%	58%	65%	0.16
Responsibility	32%	53%	64%	65%	0.15
Communication - written	24%	16%	46%	41%	0.14
Professionalism	28%	44%	52%	59%	0.13
Ethical sensitivity	20%	22%	22%	47%	0.13
Research	32%	16%	34%	47%	0.13
Thoughtfulness	60%	50%	42%	24%	0.15
Compassion	32%	44%	30%	6%	0.16
Self aware	72%	50%	70%	35%	0.17
Lifelong learning	68%	66%	58%	29%	0.18
Interpersonal skills	52%	69%	48%	24%	0.19
Openness	68%	41%	34%	12%	0.23

Table 5: Differences between disciplines in the faculty group - identified via standard deviation

	Humanities	Social Science	STEM - non engineering	Engineering	Std. Dev.
Professionalism (Value)	0%	44%	56%	90%	0.37
Professional (Attitude)	9%	24%	33%	90%	0.35
Responsibility (Value)	30%	56%	78%	100%	0.30
Responsible (Attitude)	13%	28%	56%	80%	0.30
Problem solving	13%	24%	11%	70%	0.28
Integrity	39%	60%	44%	100%	0.28
Teamwork	35%	20%	22%	70%	0.23
Compassion	43%	32%	22%	0%	0.18
Insightful	48%	20%	44%	10%	0.18
Openness	52%	40%	22%	10%	0.19
Citizenship	48%	12%	33%	0%	0.21
Spiritual	52%	32%	11%	0%	0.23
Interpersonal skills	57%	24%	11%	0%	0.24
Self aware	65%	20%	22%	0%	0.27
Inter-cultural sensitivity	52%	20%	67%	0%	0.30

Disciplinary differences among **faculty** were more striking than in the student group, possibly because of the smaller sample size (Table 5). Notable differences included

Values: Engineering selected *Responsibility* and *Integrity* at 100% and *Professionalism* with 90%. No other grouping approached this consistency, and Humanities selected these less than 40% of the time. On the other side, engineering selected *Openness, Empathy, Inter-cultural sensitivity, Citizenship,* and *Compassion* less than 10% of the time (or never) as compared to the other disciplines, which selected them much more often.

Skills: Here, the differences are similar to that in the student group but more pronounced; e.g., 100% of engineering faculty selected *teamwork*, but none selected *interpersonal skills*.

Attitudes: These results are similar to student results, with some differences; in particular, most engineering faculty selected *professional* (90%) and *responsible* (80%). Both are much higher than other disciplines. Similarly, *insightful* and *self aware* see only 10% and 0% selection from engineers.

Notable differences between **engineering faculty and engineering students** included

Values: Faculty selected *Integrity, Responsibility,* and *Professionalism* at much higher rates than students. That said, *Responsibility* and *Professionalism* were two of the top three values selected by students, while *Integrity* had a much lower student selection rate.

Skills: Both *Communication – written* and *Teamwork* saw much higher selection rates by faculty (100% and 80%) respectively, while both of these items fell roughly in the middle of the selection rates for students.

Attitudes: Notable a*ttitudes* items selected more often by students than by faculty were *Motivated/Enthusiastic, Insightful,* and *Self aware.* Indeed, *Motivated/ Enthusiastic* was the most common choice among students, but in the bottom half of faculty selections, while *Insightful* was selected by only one faculty member, and *Self aware* selected by none!

4. DISCUSSION

Our results raise several interesting questions:

1. Why do some disciplines select certain terms (e.g., *teamwork*), while other disciplines select similar meaning but different terms as more relevant to the capstone experience (e.g., *interpersonal skills*)?

2. While engineering faculty and students are closely aligned in many of their choices, what are the

implications for the items where they are not aligned?

3. Should engineering capstones consider broadening learning outcomes to include skills, values, and attitudes that other disciplines emphasize?

In this section, we will explore these three questions. In some cases, we provide answers, but in others (particularly in 3) we pose challenges to the broader engineering teaching community.

4.1. Apparent similarities that aren't

Why do engineering faculty rate *teamwork* highly, but ignore *interpersonal skills* (Figure 3)? Why do other disciplines rate *critical thinking* highly, but ignore *problem solving* (Figure 4)? Why do engineering faculty select *professionalism, responsibility,* and *integrity* as their top three choices, but students only rank *professionalism* and *responsibility* in the top three, while *integrity* is fifth (after *career orientation* and *ethical sensitivity* and tied with *thoughtfulness*)? In a linguistic sense, these pairs/triples are tightly related, and yet participants clearly view them to be somewhat distinct. These issues are likely semantic and could stem from two interrelated ideas from the psychology literature.
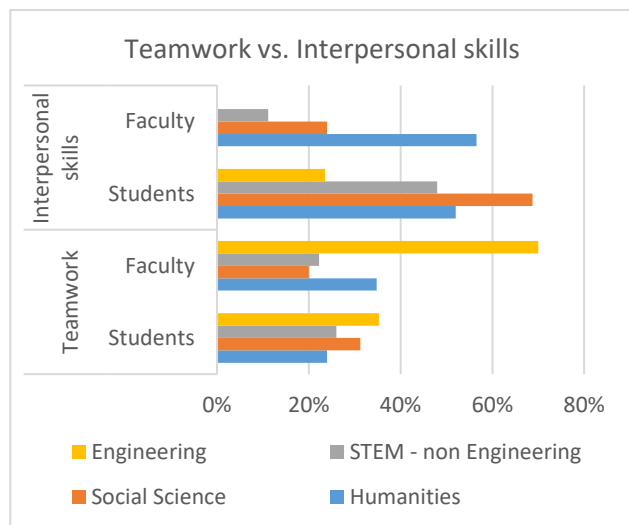

Figure 3: Disciplinary differences in the selection of the terms teamwork and interpersonal skills

In broad terms, **occupational psychosis** [18] means that we interpret life through our jobs. For example, if you say that doing your taxes gives you anxiety, a physician may offer a pill or other medical intervention, but if you say that to a professor, s/he may recommend a book or website to learn more about taxes.

Terministic screens [19] are the manifestations of occupational psychosis and help to understand the language choices that people make according to their
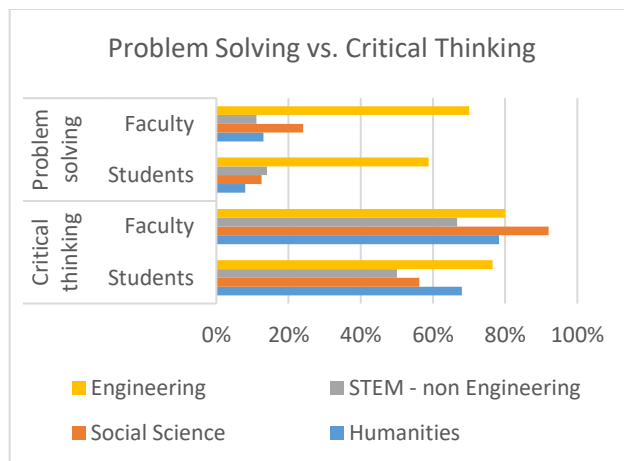

Figure 4: Disciplinary differences in the selection of the terms Problem Solving and Critical Thinking

training and profession. People in various professions have go-to metaphors that they use to create meaning in their worlds. Engineers solve problems on teams. As a result, they may use those terms to "fix" non-engineering problems. Additionally, they may not use the phrase *interpersonal skills* in their professional lives because it is a subset of *teamwork*.

The same applies to *problem solving* vs *critical thinking*. Problem solving stresses a result, while critical thinking proves students can analyze an issue (e.g., see [19]). In general, engineering underscores problem solving, while other disciplines emphasize critical thinking.

Another layer of complexity in this discussion arises due to Graduate Attributes. Engineering faculty, and through them engineering students, may be conditioned to the terms *Teamwork* and *Problem Solving* due to the accreditation process (both terms are heavily used by both CEAB and ABET).

Finally, students may view the term *Integrity* in the context of Academic integrity and therefore choose not to include it as being affected by their capstones, while faculty may have a broader interpretation.

4.2. Student and faculty alignment

Engineering faculty and students agree that professionalism, problem solving, and critical thinking are all affected by their engineering capstone, but three items have much higher selection rates among students than faculty: *Self aware, Insightful, Motivated/Enthusiastic,* and *Communication – written* (Figure 5).

We hypothesise that this increased emphasis is due to a disconnect on the faculty side between outcomes that are *affected* by the capstone verses those items that are *assessed* in the capstone – e.g., almost every engineering capstone has a large written component, so written communication is heavily assessed, but are we actually

doing anything to *affect* students' abilities in this area? If we look to the student responses, who did not select written communication as one of their top skills, the implication is that we are <u>not</u>
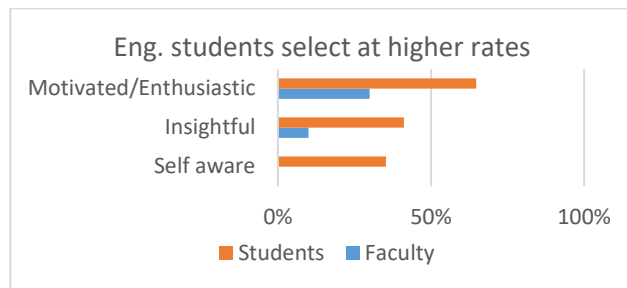

Figure 5: Items selected by engineering students at much higher rates than by engineering faculty

Finally, engineering students select the Attitude *Motivated/Enthusiastic* at the highest rates, while engineering faculty select it at the fourth lowest rate: our capstones are affecting student motivation and enthusiasm, even though we don't recognize that. Of course, the survey does not ask whether these items are affected in a positive or negative way – are we increasing their motivation/enthusiasm, or decreasing it? If the latter, we must seriously think about why this is occurring and how to mitigate it – further investigation is warranted.

4.3. Disciplinary differences

There are several disciplinary differences that cannot be explained by the semantic argument in Section 4.1. These include the overall category rankings and several items that both engineering faculty and students selected at much lower rates than other disciplines.

4.3.1. Category ranking

A profession is something that requires prolonged, specialized training. Perhaps this is the reason why both engineering faculty and students select *skills and competencies* as the most important of the three categories for capstone, while the other disciplines do not.

4.3.2. Item rankings

It is, perhaps, unsurprising that Engineers (both faculty and students) identify *professionalism*, *responsibility*, *written communication*, *problem solving*, and *teamwork* as being affected by capstones. But engineers select *openness*, *self aware*, and *compassion* at much lower rates than other disciplines (Figure 6). Is this an intentional outcome of engineering capstones, or an oversight on the part of engineering educators? Or is it simply a recognition that these skills and attitudes are not the primary focus of the engineering capstone?

Merriam-Webster defines 'compassion' as "sympathetic consciousness of others' distress together *with a desire to alleviate it*" (emphasis added). If an

engineer's reason for being is to identify societal problems, and then to find (somehow optimized) solutions for those problems, then it stands to reason that compassion could be an important engineering value.
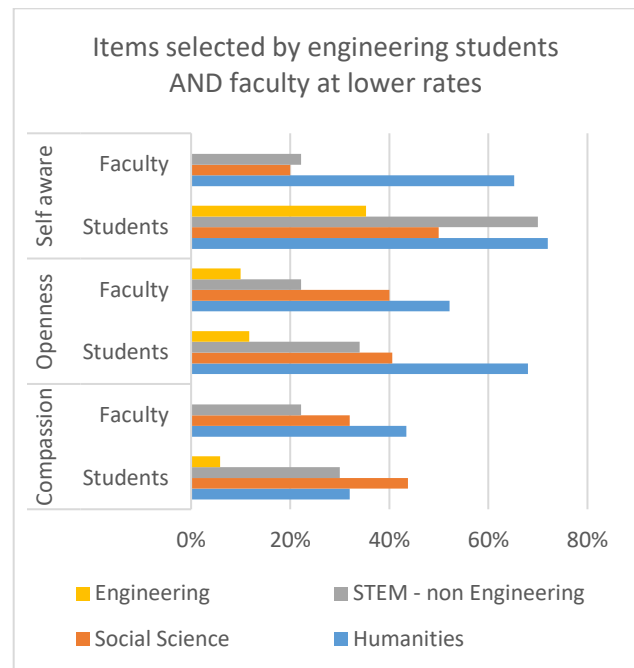

Figure 6: Items selected by both engineering students and faculty at lower rates than other disciplines

In *values*, which we defined as "your principles or standards of behavior; your judgment of what is important in life", the term *openness* ties to the dictionary definition "characterized by ready accessibility and usually generous attitude: such as […] (2): willing to hear and consider or to accept and deal with (3): free from reserve or pretense". If *compassion* can be a key tool in problem identification, then it stands to reason that *openness* is a crucial aspect of problem definition. If engineers are closed to new ideas or are approaching problems with a preconceived solution, then they are inherently limiting the solution space.

As society at large gains a better understanding of the impact of bias on decision making and policy, it behoves engineers to reflect on the impacts of their own design choices. Indeed, if engineering faculty encourage students to select their capstone design problem with compassion and openness in mind, it may avert the common issue of fourth year design students designing and building widgets. Instead, those student engineers will be better equipped to identify real problems, and then to do the hard work of consulting with the relevant stakeholders to understand the underlying issues and the potential solutions. Only then will these students be able to make a truly significant contribution to solving society's wicked problems.

Finally, *self-awareness* relates to the ability to understand our own personalities and individuality. A lack

of this trait can lead to bias, closed-mindedness, and ignorance. None of these traits is desirable in an engineer.

4.4. Limitations

Due to the small sample size, we were not able to perform a statistical analysis. Furthermore, participants were asked what was 'affected' – it is likely that participants will interpret this word in different ways (e.g., some may interpret it as analogous to 'assessed', while others may interpret it as analogous to 'changed'). Additionally, institutional influence on the capstone, and therefore its perceived affects, may be a confounding factor, but we were unable to investigate these institutional effects due to low sample sizes.

Future work includes additional surveys (to improve the sample size) and small group interviews.

5. CONCLUSIONS

While the survey results indicate that engineering students and faculty are reasonably aligned, the disciplinary differences do highlight some items deserving of reflection. In particular, we argue that engineering educators should take a step back and decide whether skills and competencies really are the most important outcome of a capstone, or whether they should instead be creating space in design courses for conversations about openness, compassion, and self-awareness. If engineering educators are truly invested in educating the whole person, then perhaps a focus on some of the 'softer' skills is in order.

Acknowledgements

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