Education of Electrical Engineering Students about Ethics and Societal Impacts in Courses and Co-curricular Activities

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Abstract*— This research explored faculty perspectives on the ethics and societal impacts (ESI) education of electrical engineering (EE) students, in comparison to other engineering disciplines. An Input-Environment-Output model underpins the work, focusing on environmental factors (courses and co-curricular settings) that could influence students' ESI knowledge. EE participation in the survey of engineering educators was lower than other disciplines (civil, mechanical, chemical), raising concerns about the culture around ESI education in EE. Instructors believed that the most common settings for ESI education of undergraduate EE students were senior capstone design and first-year introductory courses. Compared to other disciplines, fewer faculty believed that EE undergraduates were taught about ESI in sophomore/junior engineering/engineering science courses. The most common ESI topics taught to EE students were: professional practice issues, safety, and the societal impacts of technology. Fewer EE faculty taught sustainability and environmental protection issues compared to other disciplines. Within EE courses where faculty integrated ESI, the most common ESI teaching methods were engineering design, case studies, and examples of professional scenarios. Co-curricular activities such as IEEE, honor societies and research may also contribute to the ESI education of EE students. Faculty are encouraged to integrate ESI issues into all of their courses and activities.

Keywords—ethics education; pedagogy; assessment; electrical engineering

I. Introduction

It is important that electrical engineering (EE) students, like all engineers and computer scientists, are trained to consider the ethical implications of their work. This is required for accreditation of degree programs [1]. The basic requirements for microethical (individual) behavior are outlined in the IEEE Code of Ethics [2], which includes holding paramount public health,safety and welfare, striving for sustainable development, protecting the environment, avoiding conflict of interest, being honest, rejecting bribery, contributing to public understanding of technology, working within one's area of competence, crediting the work of others, avoiding discrimination, avoiding malicious actions, and helping others in their professional development. Though the primary focus of the code is on microethical issues, the code also speaks to the larger macroethical responsibilities of the profession to society (i.e., social impacts), such as sustainability. Other macroethical issues, including pro bono work, social justice, and peace, are not discussed in the code. Other disciplines have their own ethical codes [3-6], which both include and omit some of the elements in the IEEE code. In this research we explored the teaching practices of faculty with respect to ethics and societal impacts (ESI), incorporating both micro- and macroethical concepts, and contrasting individuals who reported teaching students in EE compared to other engineering disciplines.

While significant research has focused on students and their development of ethical reasoning, faculty ultimately determine how ESI is taught. Many of the leading proponents and investigators of ESI education in engineering are EE faculty, including Loui [7-8], Finelli [9], Bates [10-11], Zoltowski [12-13], and Jesiek [14]. For example, Michael Loui is one of the Principal Investigators of the Ethics CORE project and a member of the Executive Board of the National Institute for Engineering Ethics [15]. Despite many individual examples of ESI education in the literature, a broad understanding is lacking of how EE faculty teach ESI, including even if these issues are taught and, if so, where..

Lord et al. [16] conducted an international survey on electrical and computer engineering (ECE) education. Among 236 valid responses, 50% both taught and assessed moral/ethical reasoning (MER), 11% taught but did not assess MER, 1% did not teach but did assess MER, and 38% did not teach or assess MER. In contrast, 95% both taught and assessed problem solving (among n=417), and 90% both taught and assessed design (among n=384). The much lower number of valid responses for ethical reasoning compared to problem solving and design are noteworthy. Moral/ethical reasoning

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was taught primarily using lecture (49%) and assessed using locally developed tests/instruments (27%). It is uncertain how the results for ECE from this study compare to other engineering disciplines.

In a large study of faculty perceptions of ethics education by Katz and Knight [17], the 1389 responses represented 30 institutions and 34% were affiliated with an electrical engineering department. In response to "how much do you emphasize the importance of ethical beliefs in engineering", results did not differ by department affiliation alone; however, there were statistically significant interaction effects between department and gender, department and rank, and department/rank/gender. The study found significant differences in response to the question "how much do you emphasize examining beliefs and values and how they affect ethical decisions" based on department affiliation; electrical was the lowest discipline among male faculty. Electrical engineering faculty also were less in agreement with the statement "engineering curriculum should address ethical issues in multiple courses" than peers in chemical, civil, general, and industrial engineering. This study provided general information on ethics teaching and attitudes among disciplines, but lacked detail.

Romkey [18] explored the perspectives on science, technology, society and the environment (STSE) education among 180 faculty members at four Canadian institutions including 20% in ECE. Among their teaching practices, 29% of the faculty reported never having students "discuss sociotechnical issues, such as climate change or internet security, to contextualize course content"; only 9% did this very often. The vast majority of respondents (89%) indicated that instructors of engineering design courses were "responsible for STSE in the engineering curriculum", compared to only 49% agreement for instructors of "courses in which content is primarily mathematics, science or engineering science". The extent to which faculty identified various ESI-related topics (e.g. environmental impact, social impact, sustainability, ethical dilemmas) as important in engineering and used in their own classroom varied significantly. Across all 41 STSE practices, the authors concluded that for about a third of the faculty "STSE doesn't happen and is not important" and for another third "STSE is important but doesn't happen". The high quality and extensive survey results were not disaggregated by discipline.

The existing literature provides insights into the ESI education practices of engineering faculty, but generally lacks strong comparisons between EE faculty and other engineering disciplines, to determine the extent to which EE faculty are similar or different from their peers.

The theoretical framework that underpins this work is an Input-Environment-Output (IEO) model. This research focused on environmental factors (courses and co-curricular settings) that could influence students' ESI knowledge and attitudes. Finelli et al. [9] used an IEO model as the foundation for their study of ethics education from the perspective of students. They evaluated the quantity and quality of course-based and co-curricular instruction based on the responses of 3914 students at 18 institutions. These students included all engineering disciplines at the institutions, with 17% electrical. The results were not disaggregated by discipline. They did examine institutional culture as an element in the environment. However, we believe that disciplinary culture may be more influential, and predict that different engineering disciplines have unique attributes around ESI education. Unique disciplinary elements for ESI education have been previously identified among computing educators [19], biomedical engineering [20], and environmental engineering [21]. Thus, explorations of EE are appropriate.

II. Research Questions

RQ1. How does the prevalence that faculty report teaching ESI to electrical engineering students compare to other engineering disciplines?

RQ2. To what extent do engineering faculty believe that EE undergraduate and graduate students in their program receive sufficient education on ethics and/or societal issues? How does this compare to other engineering disciplines?

RQ3. To what extent do engineering faculty believe that EE undergraduate students in their program learn about ESI in different course types and co-curricular activities? Is there evidence that some programs use an ethics-across-the-curriculum approach? Are there correlations between the number of course types for ESI learning and perceptions of ESI educational sufficiency? How do these results compare to other engineering disciplines?

RQ4. What ESI topics, teaching methods, and assessment methods are used in courses for EE students? How do these compare to other engineering disciplines?

RQ5. To what extent do faculty educate EE students about ESI in co-curricular settings? Do ESI topics and educational approaches vary among different types of EE co-curricular settings?

III. Methods

This exploration of faculty teaching practices of ESI to EE students was embedded within a larger study on ESI education. Two phases are relevant to this study: (1) quantitative data from a large national survey and (2) qualitative data from the survey and faculty interviews.

A. Survey

There were two survey instruments used to gather quantitative data. These included questions to characterize individuals' personal teaching practices for ESI in courses (both undergraduate and graduate) and co-curricular settings, as well as their perceptions of settings for ESI education of undergraduate students in their program. The two surveys included nearly identical questions but were presented to the survey takers in a different order. The curricular survey began with questions about ESI education in courses; the co-curricular survey began with questions about ESI education in informal settings. Both surveys ended with demographic items. The survey development process included pilot testing and interviews, and has been described previously [22]. The survey questions have also been previously described [23]. Individuals could skip any of the questions on the survey, resulting in different numbers of responses for particular items.

Individuals were invited to participate in the survey via email from February to April 2016. This included 6173 invitations emailed to individuals, as well as invitations to list serves of four divisions of the American Society for Engineering Education (ASEE) and other groups. All disciplines within engineering were equally sought-out to participate in the study. For example, the professional societies associated with each discipline and cross-cutting groups (e.g. Society of Women Engineers, Tau Beta Pi) were asked to email survey invitations to the faculty mentors of their university chapters. Only the American Society of Civil Engineers (ASCE), American Institute of Chemical Engineers (AIChE), American Institute of Aeronautics and Astronautics (AIAA), Engineers Without Borders (EWB), Engineering World Health (EWH), and Bridges to Prosperity (B2P) consented. For all groups (including IEEE), the first author emailed individual faculty mentors using self-compiled lists developed from online information. Self-compiled lists of the faculty mentors of university chapters of engineering honor societies were emailed, as well as REU site PIs/coPIs, and engineering competition mentors. Further details on the survey distribution methods have been previously described [22-24].

Because the low representation of EE faculty among respondents was of concern, in April 2016 the curricular survey invitation was emailed to 86 EE instructors who appeared from their websites to have an interest in ethics/societal impact topics; 6 additional survey responses were obtained (7%). The only other engineering discipline directly solicited in this manner to participate in the curricular survey was nuclear engineering (30 individuals invited, 2 responses, 7%).

B. Survey Respondents

First, the pool of responses representing EE were determined. There were 116 faculty considered EE based on teaching electrical engineering students (with or without computer engineering) and no other main engineering disciplines (e.g. chemical, civil, environmental, mechanical, materials). Among EE faculty, 36 (31%) also taught computer engineering students, not surprising given that many departments are "electrical and computer engineering" (another 59 survey respondents taught EE and other disciplines, but these responses were not included in the EE data set, since it would be unclear if their "program" was electrical or not). Among the 116 EE faculty, 104 different institutions were represented (98 U.S., 3 Canada, 1 Sweden, 1 Turkey, 1 Pakistan). Among the EE respondents, 76% responded to the co-curricular survey and 24% to the curricular survey.

When comparing to other engineering disciplines (non-EE), 1222 responses were used; this did not include survey responses lacking an indication of the engineering disciplines that they taught. Among the non-EE comparators, 74% responded to the co-curricular survey (not significantly different than the ratio of curricular vs. co-curricular respondents in EE).

The demographics of the EE respondents differed somewhat from the non-EE respondents (Table I), for example, a higher percentage of full professors, more at religiously-affiliated institutions, and fewer females.

TABLE I. DEMOGRAPHICS OF EE AND NON-EE SURVEY RESPONDENTS

Characteristic	EE (n=116)	Non-EE (n=1222)
Institution type, %		
Doctoral	79	80
Master's	12	13
Bachelor's	8	7
Community college	1	0.4
Institution control, %		
Public	67	73
Private	33	27
Religiously-affiliated+	14	8
Rank, %		
Full+	43	34
Associate	25	28
Assistant*	10	18
Others	21	19
Gender, % *	(n=111)	(n=1189)
Female	17	34
Male	83	66
Grew up primarily in US	(n=102)	(n=1089)
Yes	75	79
No	25	21
Race/Ethnicity, %	(n=100)	(n=1092)
White, non-Hispanic	71	77
Hispanic	6	5
Black / African American	5	3
Asian	15	9

EE vs. non-EE: * $p<0.05$, + $0.05 < p < 0.10$

C. Quantitative Results Analyses

Comparisons among two groups (such as EE vs. non-EE) were conducted initially in Excel using chi-square tests. Given the low response numbers, this was then followed by Fisher's exact test when the significance from the chi-square tests was 0.2 or lower. Fisher's exact tests were conducted with a threshold for significance in two-tailed tests of 0.10 or lower [25]. Non-parametric Spearman's rho correlations were conducted in IBM SPSS v. 24.

D. Qualitative Results: Write-In Comments and Interviews

Near the end of the survey there was an open-ended question that asked respondents to "share your thoughts about the education of engineering students regarding broader impacts and ethical issues." There were 29 EE faculty who wrote-in comments. These responses have been previously coded [26], and key results specific to the EE faculty will be highlighted.

On the survey, 230 individuals indicated an interest in possibly participating in an interview on ESI education, including 27 who taught EE students and other disciplines. From among this group, 54 were invited to participate in interviews (including 12 who taught EE students). The specific criteria used to select and interview these individuals are described in detail in [27]. Thirty-seven interviews were conducted, including 5 with EE faculty. Detailed examples of teaching settings and opinions on institutional context from these interviews are included in this paper.

E. Limitations

The study included EE responses representing about 30% of the total number of U.S. institutions with ABET EAC-accredited EE Bachelor's degrees (which numbered 322 programs at 309 institutions in 2018 [28]). This response rate on an institutional basis would typically be considered representative (95% certain with 8% margin of error [29]); but that assumes that the individuals who responded had good knowledge of ESI education within their program. It is also of concern whether the EE survey respondents (110 U.S.) are representative of EE faculty more generally (5972 reported by [30]). Although the numerically estimated margin of error is 9% at a 95% confidence level, the individuals who responded to the survey may be more likely to integrate ESI into their teaching and/or care about ESI education than average faculty members, based on the survey invitation language which indicated that the study focused on ESI education practices. The study population is largely U.S.-centric, and should not be considered to represent international contexts.

IV. Results and Discussion

RQ1. EE Faculty Interest in ESI Relative to Other Disciplines

The survey gathered a lower percentage of EE faculty responses relative to other disciplines (Table II; e.g. 1.9% EE vs. 2.8% mechanical, p=0.0057 in chi-square test with Yates correction). This seemed to result from a somewhat lower co-curricular survey response rate among IEEE and IEEE-HKN faculty mentors compared to the mentors of other professional and honor societies (Table II). The representation of EE faculty among the mentors of other groups invited to the co-curricular survey (e.g. Society of Women Engineers, Tau Beta Pi) is uncertain. The curricular survey invitations may have reached a smaller percentage of EE faculty, based on ASEE membership (Table II). The apparently lower interest in ESI by EE faculty, based on a lower percentage of survey respondents, is similar to the results of Katz and Knight [17]. Further research is needed to explore whether lower participation of EE faculty in the ESI survey is due to lower interest in ESI or other reasons.

TABLE II. Survey Respondents from Different Disciplines

Characteristic	EE	Mech	Civil	Chem	All
US T/TT faculty 2015 [30]	5972 [1]	4808	3426 [2]	1959	26,839
Respondents, 1 discipline, n	116	133	214	72	
Percentage of US faculty	1.9%	2.8%	6.2%	3.7%	
Multiple disciplines, n	175	300	296	143	1448
Percentage of US faculty	2.9%	6.0%	8.6%	7.3%	5.4%
Professional society	IEEE	ASME	ASCE	AIChE	
US student chapters	227	450	285*	218*	
Advisor names emailed	235*+	166*	261	151	2318
Respondents	32	33	51	37	444
Response rate*, %	14	20	18	17	19
Honor society	HKN	PTS	XE	OXE	All
US student chapters	166	177	137	76	1013
Advisor names emailed	107*	109*	132*	37*	673
Respondents	9	20	31	9	106
Response rate, %	8%	18%	23%	24%	16%
ASEE Division members[31]	832	889	597	522	12,000^
% ASEE / US T/TT faculty	14%	18%	17%	27%	45%

T/TT = Tenure/Tenure Track; [1] EE + ECE; [2] Civil + Civil/Environmental; + at some institutions multiple advisors were listed and contacted, * response rate calculated based on the number identified; ^ [32], includes some non-faculty

Among the survey respondents, somewhat more EE faculty taught no topics related to ESI (14%) compared to peers in other disciplines (11%); the difference was not statistically significant (Fisher's exact test p=0.27). However, it is presumed that the actual percentage of faculty who do not teach ESI is higher, and that the survey respondents were over-represented in those who teach ESI. By comparison, Lord et al. [16] reported that 36% of their ECE faculty respondents did not teach moral/ethical reasoning. It is worth considering that while related, ESI and moral/ethical reasoning are likely perceived differently by faculty.

Perhaps more EE faculty than peers in other disciplines are dedicated to technical issues, and/or don't feel comfortable teaching ESI. One EE faculty member teaching at an undergraduate-focused institution noted in an interview:

> *many faculty don't feel qualified to teach ethics and it's not a high priority for them. We have, I think, a split within our faculty, and this split probably mirrors splits within a lot of other faculty across the country… a subset that is very technically oriented, very focused on their research and their goal is to produce students with the best technical knowledge… [and another group] who want to create a lot of opportunities… it's really hard to get people to do ethics just because ABET requires it….*

Another interviewee from EE at a large, public, research-intensive institution described:

> *there is fierce resistance from the rest of the department of electrical and computer engineering. …the faculty generally believe that all engineering knowledge is technical, they seem not to understand that engineering ethics is part of the non-technical knowledge that engineers need to have…. There's this feeling that if it's not technical, it's not something we want to be teaching in the department.*

But the need for teaching ESI due to accreditation was cited as a wedge for its inclusion. The faculty being interviewed generally did not contrast EE with other engineering disciplines, which is not surprising since most individuals would only have detailed knowledge of their own discipline.

RQ2. Sufficiency of ESI Education

Among the faculty who taught EE students, 30% felt that undergraduate students in their program received sufficient education on ESI (Table III), not significantly different from other engineering disciplines. One EE faculty member noted on the survey, "My sense (at least locally) is that ethics is reasonably well covered in courses, but that it is more difficult to capture the broader impacts on society (justifiably so; this is more difficult to define, too)." More faculty felt that EE graduate students in their program did not receive sufficient education on ethics and broader impact, 58%, compared to 39% for undergraduate students. One survey comment noted, "Graduate students are too focused on research and advisers do not care in general about these topics unless they are publishing in that specific area." More EE faculty believed that graduate education on ESI was sufficient compared to other engineering disciplines (p=0.04).

TABLE III. PERCEIVED SUFFICIENCY OF ESI EDUCATION

Sufficient education on ethics and broader impacts?	EE, %		Non-EE, %	
	Undergrad n=87[a]	Grad n=69[b]	Undergrad n=997	Grad n=780
1. Yes, but too much; time better spent on other topics	0	0	1	1
2. Yes, a sufficient amount	30	26	30	17
3. A sufficient amount of ethics, but insufficient on the broader impacts of technology	18	14	16	9
4. A sufficient amount on the broader impacts of technology, but not enough ethics	13	1	12	11
5. No, not enough	39	58	41	62

[a.] Unsure responses not included in n or the percentages; [b] Unsure/not applicable responses not included

RQ3. Settings for Undergraduate ESI Education

The survey asked where individuals believed that undergraduate students in their program learned about ESI; results are summarized in Table IV. Over half of the EE respondents believed that students learned about ESI in capstone design, similar to non-EE faculty. Fewer EE faculty compared to non-EE faculty believed that their students learned about ESI in technical courses such as sophomore/ junior engineering/engineering science (ES) courses and design-focused courses in the sophore to senior year. This implies lower integration of ESI in the middle years of EE curricula in comparison to other disciplines. In fact, a larger percentage of EE faculty taught ESI topics in their own core courses (37% ES and 29% design-focused) compared to the percentage who felt that undergraduate EE students learned about ESI in these course types; perhaps their courses with ESI integration were electives rather than required courses or taught by multiple instructors such that the course did not always include ESI. Full ethics courses were noted at four institutions that were also rated to have sufficient ESI education for EE students.

TABLE IV. SETTINGS FOR ESI EDUCATION, % RESPONDENTS

Learning Setting for ESI	EE n=95	Non-EE n=1023
Senior capstone course	65	63
First-year (FY) introductory course	44	45
Humanities/social science (HSS) course	33	32
Professional issues course	27	27
Sophomore/junior engineering/ES course	23	39*
Design-focused course sophomore–senior	23	34*
Co-curricular engineering service group	23	24
Co-curricular professional society	21	25
First-year (FY) design focused course	18	21
Full course on ethics	12	18
Average # course settings	*3.0*	*3.4*

* $p<0.05$

There appeared to be different levels of knowledge about the EE curriculum and/or interpretations of what "counts" as ESI education among the survey respondents. For example, at one institution with three respondents from EE, two faculty indicated six settings for ESI instruction of EE students while one respondent only identified three settings. All three agreed that capstone design and HSS courses included ESI and that students did not learn about ESI in ES courses or a full course on ethics; all other settings had disagreement among the three raters. A second institution with three EE survey respondents had a similar level of disagreement; the total number of ESI educational settings identified by the respondents ranged from two to six with complete agreement only on ESI in senior capstone design and no ESI in ES courses, a professional issues course, or a full course on ethics.

The ESI teaching settings identified by faculty in this study differed somewhat from the course settings where students reported learning about ethics and those that were the "most influential" (i.e. that they would be most likely to consider when facing an engineering ethical dilemma) in Finelli's earlier work [9]. Among upper-division students at 18 institutions, 80% learned about ethics in an introductory engineering course, 59% in a non-engineering course, 53% in an advanced engineering course, and 29% in capstone design. The most influential settings identified by the upper-division students were an introductory engineering course (33%), an advanced engineering course (26%), capstone design (11%), and a non-engineering course (9%); these do not align particularly well with the ESI teaching settings reported by EE faculty. The differences between the student results in [9] and the current study of faculty include: our inclusion of ESI while students were only asked to consider ethics (which they may interpret as microethics, and not include broader societal impacts typical of macroethics); differences between instructor perceptions of teaching intent versus student learning and what they remember; differences among the institutions and disciplines in [9] compared to the wider range in this study.

Within interviews, institutional culture was discussed by the EE faculty as both a positive and a negative toward ESI education. An EE faculty member at a religiously-affiliated institution described a supportive institutional culture: "Our faculty very much champion our students thinking through who they are in their faith, that's really kind of the big picture of how we view ethics. …that's so integrated with all of the worldview of every person in [engineering]." In contrast, an EE faculty member at an international institution described that most faculty were not aware of, or interested in, how he teaches a required Science Technology Society (STS)-focused course. In addition, most instructors at the university do not integrate non-technical topics into their courses. While his ethics-focused course is appreciated by the administration because it fulfills the ABET ethics requirement, it is not given high priority at the institution.

On the survey, one individual who identified ES courses as the only setting for ESI education in their undergraduate program noted, "Demonstration of [ESI] outcomes are even part of ABET requirements. However, these outcomes are not often explicitly taught or integrated into the curriculum, its like we expect the students to just 'get it', when in reality they often don't." Another respondent who identified senior capstone design and other design-focused courses in the sophomore to senior year as settings for ESI education of EE students in their program noted: "I think currently in a number of programs it is merely something to be checked off to meet ABET, rather than being integrated into every aspect of the curriculum."

ESI across the curriculum seems less common in EE than other engineering disciplines. Among 89 individuals who reported one or more settings where undergraduate EE students learned about ESI, 25% included a core engineering/ engineering science course and three or more total course types. Among non-EE instructors, 43% met these same criteria for ESI across the curriculum (n=423 of 975). There were five institutions for ESI education in EE that were rated as sufficient for ESI education and with 4 or 5 course settings for ESI education. Faculty from all of these institutions reported that ESI was integrated into both a first-year introductory course and capstone design. None of these institutions required EE students to take a full course on ethics.

The sufficiency ratings for EE undergraduate ESI education did not correlate with the number of settings for ESI education (Spearman correlation -0.05, p=0.639), in contrast to a weak but significant correlation among other engineering disciplines (Spearman correlation -0.171, p<0.001); these data are summarized in Table V. There appear to be widely varying opinions among EE educators on what constitutes sufficient ESI education. Three EE instructors who believed undergraduate students received sufficient education on both ethics and broader impacts cited senior capstone design as the sole source of ESI education. Another EE instructor characterized both ethics and broader impacts education of undergraduates as insufficient, despite indicating that capstone design, a first-year design course, a professional issues courses, and sophomore/junior engineering courses included ESI. Among EE faculty there is not an indication that the quantity of different learning settings including ESI (i.e. number of different course types) equates to sufficient quality of ESI education.

TABLE V. AVERAGE NUMBER OF ESI EDUCATIONAL SETTINGS AMONG THOSE WITH DIFFERENT SUFFICIENCY RATINGS

Sufficient education on ethics and broader impacts?	**Avg Number of Settings with ESI**	
	EE	Non-EE
1. Yes, but too much; time better spent on other topics	NR	3.8
2. Yes, a sufficient amount	3.2	3.9
3. A sufficient amount of ethics, but insufficient on the broader impacts of technology	2.7	3.5
4. A sufficient amount on the broader impacts of technology, but not enough ethics	2.2	3.1
5. No, not enough	3.0	3.0

NR = no responses at that sufficiency rating

RQ4. Courses for ESI Instruction of EE Students

Faculty teach a variety of ESI topics in courses for EE students (summarized in Table VI), averaging 4.5 different topics per person, compared to a higher average of 5.5 ESI topics among non-EE instructors. These topics may not be all included within a single course, but rather represent the topics an individual teaches among all of their undergraduate and graduate courses. One EE faculty member teaching a full course on STS taught 17 different ESI topics. The most prevalent ESI topics are similar among both EE and non-EE faculty: professional practice issues, safety, societal impacts of technology, and engineering codes of ethics. A smaller percentage of EE faculty taught students about sustainability and environmental protection than their peers in other engineering disciplines, despite the inclusion of these requirements inside the paramountcy clause in the IEEE Code of Ethics [2]. Three other ESI topics were also taught by a smaller percentage of EE faculty members than peers in other engineering disciplines: social justice, poverty, and bioethics.

TABLE VI. PERCENTAGE OF RESPONDENTS TEACHING ESI TOPICS

ESI Topics [a]	**Courses**		Co-curricular mentored by EE^			
	EE n=111	Non-EE n=1177	All n=119	IEEE n=34	Honor n=24	Research n=18
Profess'l practice issues	51	56	56	71	42	50
Safety	49	44	38	32	8	**83**
Societal impacts eng&tech	47	51	39	35	29	39
Engineering code of ethics	44	42	32	44	33	33
Eng decisions under uncertainty	40	46	24	21	13	**44**
Ethics in design	36	37	14	21	8	22
Ethical failures / disasters	32	41	18	21	8	19
Responsible conduct of research	31	31	29	24	13	**83**
Risk and liability	24+	34	13	18	4	17
Sustainability	23*	43	22	**26**	8	11
Ethical theories	15	21	6	9	4	11
Environmental protection	14*	34	18	26	4	22
Social justice	10*	17	8	0	4	0
Engineering and poverty	7*	15	14	11	13	10
Privacy and civil liberties	7+	13	10	9	4	**28**
Bioethics	2*	8	2	0	0	**11**
NO TOPICS	14	11	12	6	**29**	0
Average # ESI topics	*4.5**	*5.5*	*3.7*	*3.9*	*2.1*	*5.2*

[a] A low percentage of EE faculty that did not differ significantly from non-EE faculty taught: nanotechnology ethics (5%), other (5%), war, peace and/or military applications of engineering (7%); Comparing EE to non-EE: * p<0.05; + 0.05<p<0.10; ^ = some described two co-curricular activities

In total the faculty described 100 courses for EE students where they integrated ESI on the surveys; non-EE faculty described 1066 courses. On average, EE faculty used 4.3 ESI teaching methods and 1.9 ESI assessment methods per course when they integrated ESI; this was similar to non-EE instructors who averaged 5.1 ESI teaching methods and 2.1 ESI assessment methods. The use of multiple teaching methods is likely a best practice, reaching students with different preferred learning styles and encompassing the four developmental domains described by Vanasupa et al. [33].

The percentage of EE instructors who reported using various teaching methods for ESI within individual courses are summarized in Table VII. Case studies, professional scenarios, and engineering design were widely used. A higher percentage of EE faculty compared to non-EE faculty taught ESI via engineering design. Fewer EE faculty taught ESI using lectures, case studies, in-class debates / role plays, and videos. To contextualize these results using data reported in the Finelli et al. study [9], 88% of the upper-division students reported learning about ethics from a presentation by professor (similar to "lecture"). Students reported the most influential pedagogy as a presentation by a professor (33%) followed by a presentation by a person speaking about their own experiences (23%) and guest speakers/working engineers (14%).

Among ESI assessment methods (Table VIII), homework assignments graded with a rubric were the most common. EE instructors differed from non-EE instructors only in lesser use of test/quiz questions and other methods.

TABLE VII. ESI TEACHING METHODS IN COURSES

Teaching Methods [a]	**EE %**	**Non-EE %**
Case studies	56*	70
Professional scenarios	56	62
Engineering design	56*	44
In-class discussion	53	73
Lectures	53*	70
Project-based learning	39	41
Guest lectures	30	31
Videos	20*	30
Reflection	20	27
Problem solving heuristics	14	15
Think-pair-share	13	17
Service-learning, community engagement	13	14
In-class debates, role plays	10*	23

[a] Fewer than 10% of EE faculty used humanist readings and moral exemplars; * $p<0.05$

TABLE VIII. ESI ASSESSMENT METHODS IN COURSES

Assessment Methods	**EE %**	**Non-EE %**
Homework assignment, essay, papers graded with rubric	40	43
Group-based written assignment	36	36
Reflective essays	33	42
Test and/or quiz questions	27*	39
DO NOT ASSESS	19	14
Team ratings	14	16
Individual homework with right/wrong answers	13	17
Surveys	9	10
Other	6*	14
Individual standardized assessment method (e.g. DIT)	0	2

* $p<0.05$

Examples of ESI integration into different types of courses for EE students are described in the following paragraphs.

In FY introductory courses for EE students (n=14) the most widely used ESI teaching methods were examples of professional scenarios (86%), case studies (71%), and in-class discussion (64%). Common assessment methods were individual reflections (57%). An EE faculty member commented: "Faculty resistance and curricular time pressure make these issues "extra" and not valued. Introductory courses are orchestrated so as to cover ethics in one class, among other freshman integration topics."

Eighteen engineering science/engineering courses that integrated ESI were described by EE instructors, such as: ECE Laboratory I, Instrumentation and Imaging, Engineering Electromagnetism, Microcontrollers, Systems Programming, Introduction to Power Systems and Machines, and Electronics Measurement Techniques. The most common ESI instruction and assessment methods in these courses were discussion (72%) and test/quiz questions (39%). ESI instruction was not assessed in 33% of these courses.

One EE instructor at a religiously-affiliated institution commented on his junior Signals and Systems class: "I want to bring in problematic social issues… [but] I don't have a broad repertoire of questions that I can just reach in and show ethical dimensions of the Fourier transform…. I can do a little bit to at least open their eyes, and open my own eyes, to recognize when their technical analysis meets this problematic social context, I can hopefully train them to ask the question, 'who am I as I'm doing this analysis'… that leads them to the ethical questions." This indicates that microinsertion might be an appropriate way to incorporate ESI into core technical courses, similar to Davis [34].

Capstone design was the most commonly described setting for ESI education by EE faculty (n=31). This aligns with the fact that faculty at 66% of the institutions identified capstone design as a site for ESI education. The literature includes examples of ESI education in EE capstone design [35]. ESI issues appeared to be commonly integrated into the design projects (74%), and therefore assessed using group-based written assignments (55%). An EE faculty member described the integration of ESI into capstone design during his interview: "We were getting ready for ABET review and … ethics was not being addressed at all so we hurriedly threw that into senior design but it's too little, too late… it's not to the depth I'd want." He went on to describe, "We do it really more organically and holistically because what we found is every time we try to teach ethics it's seen as an add-on, a bolt-on to the program, it's outside students' purview of what engineering should be so we often tend to let ethical issues arise within a team, we're very hands-off on running it." One method they use is a design canvas approach (based on the business model canvas) and he stated "I think it's helped a lot, having them create representations of their design that contextualize these ethical questions." In another case, an institution largely pulled ESI out of capstone design and created a separate 1-credit ethics and professionalism course; the EE instructor described this change as "very positive".

There were 26 institutions from which individuals identified professional issues courses as a site for ESI education, but only 9 EE instructors described these courses on the survey. Professional issues courses have been previously described as a common site for ethics education [36]. An EE faculty-member noted that teaching ESI in professionalism courses was "easier" compared to technical courses because "we are given permission to talk about broad, complex social issues."

There were 14 EE faculty who reported teaching ESI in graduate-level courses. It is likely that the majority of faculty at institutions that award doctoral degrees teach a graduate-level course, so this may indicate that the majority of graduate-level EE courses (~83%) do not include ESI. This is perhaps not surprising given the lack of external motivations like ABET to integrate ESI. Examples of graduate level courses with ESI (some cross-listed with senior-level undergraduate courses) included: Photovoltaic Systems Engineering, Sustainable Power Production, and Embedded Systems Design. Among the 12 graduate-level EE courses described, common ESI teaching methods were lectures (67%) and design (66%). The most common ESI assessment method was individual assignments graded with a rubric; 33% did not assess the outcomes of ESI education.

RQ5. Co-Curricular Settings for ESI Education

Co-curricular activities for EE students offer opportunities for learning about ESI, with the topics commonly included shown in Table VI. The co-curricular activities described by EE faculty members included professional societies (e.g. IEEE and the Society of Women Engineers), honor societies (e.g

Tau Beta Pi, HKN), design competitions (e.g. Electric Vehicle Competition, Solar Boat Design), research (REU), and others (e.g. Nerd Girls). One EE faculty member contrasted course-based and co-curricular ESI instruction: "When they get it in an informal setting it means more." The majority of informal learning settings do not assess outcomes associated with ESI (88%). The co-curricular types with a high number of EE responses are summarized in Table VI and discussed below.

Research experiences cover a rich array of ESI topics (average 5.2), including responsible conduct of research, safety, uncertainty, and privacy/civil liberties. An REU mentor explained: "First, they must complete online training on responsible conduct of research. Next, we meet regularly as a group and talk about progress. In those discussions, we often talk about the end goals of the research and how they relate to society." Another research mentor noted, "Their individual research projects are always designed within a context of their effects upon society, individuals, and the environment." One summer REU site had a particular focus on ethics that included "A series of sessions with text cases and short videos that students discuss in small groups… typically six sessions." Links between research experiences and ESI education of students have been previously described [37,38].

IEEE chapters commonly included ESI topics, such as professional practice issues and sustainability. One mentor stated, "IEEE is a service organization, many of the sponsored projects target issues in society. Tutoring and projects related to peer education are also strongly encouraged and supported." Another IEEE mentor noted that ESI was incorporated "Mainly through Friday lunch meetings where we have guest[s] from industry and academia discussing career and engineering issues. Also, we have teams in the IEEE Xtreme Contest and discuss the honor code as faculty proctor the event." Another example was the "IEEE Global Humanitarian Technology Conference where students present on their humanitarian technology projects." ESI education via professional societies has been discussed for the American Society of Civil Engineers (ASCE) [39, 40] and the American Institute of Chemical Engineers (AIChE) [41], but not previously for IEEE.

A large percentage of IEEE-HKN honor societies also incorporated ESI (71%). One example was, "Each student does a self-assessment by writing an application essay including the attributes of honesty and integrity in engineering. These application essays are reviewed and evaluated by current members of the honor society. One or more speakers per year address issues of ethics and broader impacts from experience in their engineering practice." Another ESI example is, "Our HKN chapter has participated in two recent design projects, one on energy efficient lighting in the dormitories, and a second one on off grid PV design for a non-profit group." Another HKN mentor noted, "Our students volunteer to tutor freshman so they learn how to give back to incoming students." K-12 outreach activities were common among both IEEE and IEEE-HKN chapters, such as "Hands-On Science activities in which the University students assist high school students construct, troubleshoot and test logic circuits."

Thus, there are a variety of ways that co-curricular activities can contribute to students' awareness of ESI, and development of ethical reasoning abilities. However, because these activities are self-selected by a portion of students, co-curricular settings should not be relied upon as the sole source of ESI education. A holistic understanding of both curricular and co-curricular settings for ESI education should be developed; a good model from civil engineering has been published [42].

V. Implications and Conclusions

The majority of the EE survey respondents felt that the ESI education of both undergraduate and graduate students was not satisfactory, in terms of either broader impacts or ethics. All faculty have an ability to improve the situation, by integrating societal impact issues and/or ethics into all of the courses that they teach. Examples from EE faculty were found in all types of courses. This can include microinsertions, such as discussing the real-world contexts of engineering problems. A deeper exploration of ESI in a few targeted courses is likely needed to reach higher levels of cognitive sophistication and perhaps behavioral impacts. The thoughtful design of this ESI integration at a program-level would lead to an ESI-across-the-curriculum approach that some have deemed impactful [43-45]. Undergraduate programs should engage in this activity to ensure that they are meeting the recently revised ABET EAC Criterion 3 outcome 4 [1].

The research results indicate that EE faculty might benefit from seeking out ESI educational models from other disciplines. Sustainability and environmental impacts are more common in other disciplines. Teaching methods such as debates or role-plays may be transferable. A particular weakness appears to be in the area of assessment. Standardized assessment methods have been developed and are applicable to a range of disciplines (e.g. [46]). Assessments might include short reflections or a few questions added to a test or quiz. EE might also consider partnering with other disciplines (e.g., philosophy) in multi-disciplinary courses. These courses may expose EE students to ESI topics and teaching approaches that might otherwise be missing from their education.

On-going research is seeking exemplary ESI education practices, based on triangulating the perspectives of the instructor, students' self-assessments, alumni of these learning settings, and assessment of student work by the research team. The goal is to identify impactful macroethics instruction practices that might be transferable to a range of disciplines and institutions. In addition, a more detailed understanding of what leads faculty to particular ESI teaching practices, including faculty development approaches, is needed.

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