An Overview of the Microethics and Macroethics Education of Computing Students in the United States

Angela R. Bielefeldt, Madeline Polmear
Dept. Civil, Environmental, Architectural Engineering
University of Colorado Boulder
Boulder, CO, USA
Angela.Bielefeldt@colorado.edu

Christopher Swan
Dept. Civil and Environmental Engineering
Tufts University
Medford, MA, USA

Daniel Knight
Dept. Mechanical Engineering
University of Colorado Boulder
Boulder, CO, USA

Nathan Canney
Dept. Civil and Environmental Engineering
Seattle University
Seattle, WA, USA

***Abstract*—The literature does not include a good synthesis of how ethics, particularly macroethical issues, are integrated into the education of computing versus engineering students. Survey responses from faculty who teach computing students (n=188) were compared to other engineering disciplines (n=1161). The most common topics taught by the computing respondents were: professional practice issues (64%) and the societal impacts of engineering and technology (62%); these same topics were the most prevalent among other engineering disciplines. Privacy and civil liberties were taught by 48% of computing educators (vs. 9% of non-computing), while six topics were taught less frequently to computing students. Ethics and societal impact topics were most commonly taught to computing students using discussions and case studies in sophomore or junior level core engineering courses and senior capstone design. Some ethical topics were also infused into co-curricular activities. Among computing instructors, only 32% felt that undergraduate education on both ethics and broader societal impacts in their program was sufficient. Fewer respondents (23%) felt that graduate education of computing students on these issues was sufficient. These perceptions were similar in other engineering disciplines. The research results suggest improvements for the integration of ethics into the education of computing students.**

Keywords—computer science; computer engineering; engineering curriculum; ethics; faculty; pedagogy

I. Introduction

Given the vast societal impacts of engineering and technology, it is imperative that education in these fields trains individuals to consider the ethical implications of their work. This includes an array of microethical and macroethical issues [1]. Microethics are largely individual responsibilities, while macroethics encompasses the broader responsibilities of the profession to society. The ethical development of engineering students has been modeled using an input-environment-output model [2], where the environment includes courses, co-curricular activities, and institutional culture. As well, the Four Domain Development Diagram (4DDD) has been proposed as an effective method to improve ethical reasoning [3]. The model includes cognitive, psychomotor, affective, and social domains for learning. It also includes a motivation system to drive learning that revolves around interest, value, and autonomy. While these models have been proposed for engineering, they should apply more broadly to other disciplines given their fundamental characteristics.

Computing has been characterized as a unique discipline [4] related to science, math, and engineering [5], and includes five distinct sub-disciplines: computer engineering (CE), computer science (CS), software engineering (SE), information technology (IT), and information systems (IS) [6]. The computer engineering end of the spectrum is the most theoretical and similar to electrical engineering, while the information systems end of the spectrum is the most business oriented [7]. The Association for Computing Machinery (ACM) has developed curriculum guidelines that characterize the body of knowledge associated with each of the computing sub-disciplines [8-10]. These include elements related to ethics and societal impacts (ESI), with specific topics required such as intellectual property (IP), legal issues, privacy and civil liberties, and sustainability. The recommended minimum number of lecture hours for these topics varies among the SE, CE, and CS programs. Ethics is also included within the ABET accreditation standards for software and computer engineering degrees under the Engineering Accreditation Commission (EAC) and for computer science degrees under the Computing Accreditation Commission (CAC) [11-12]. Both engineering and computing disciplines also have codes of ethics to guide practice (e.g. ACM, IEEE, NSPE) [13-16].

A 2005 survey of 50 CAC-accredited computer science programs found that 55% of departments required an ESI of computing course taught within the computing department, 30% of the program incorporated discussions of ESI into other computing courses, and 15% required their students to take an ethics course outside of computing (typically philosophy) [17]. While the number of credits and location of these courses in

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the curriculum were reported, the specific topics covered in regards to ESI were unclear. A larger 2005 survey explored the inclusion of social and professional issues in computer science curricula, with 251 responses from CS programs (47% from department chairs) including 57% from non-accredited programs [18]. The survey focused on whether there was inclusion of ESI or not, types of courses, hours of coverage, teaching methods, topics (of 10 choices), and perceived importance. This was an excellent and detailed study, but at this point the data is more than 10 years old. In a more detailed study of ethics education in computing programs at four institutions [19], requirements were compared at both the undergraduate and graduate (Master's degree) levels. Among the Master's students at these institutions, 59% indicated that they had been exposed to ethics in their graduate studies, compared to only 31% ethics exposure in their undergraduate studies. About half of the Master's students and faculty at these institutions supported the notion that an ethics course should be required in CS Master's degrees, and about 70% were supportive of an elective course in ethics being available to graduate CS students. Specific examples of ethics integration into CS courses in the first-year, core CS courses, and CS capstone design have also been published [20-23].

Other large studies of ethics education have included computing among other engineering disciplines. Finelli et al. [2] conducted a student survey to learn about ethics education; the 3,914 student respondents represented 18 institutions and a wide range of engineering disciplines, including 16% from computer or software engineering. The results were not differentiated by disciplines but noted that students had experienced an average of 6.6 different types of curricular ethics education experiences, largely in introductory engineering courses and non-engineering courses, and most commonly via a presentation by a professor. These settings were also identified as the "most influential" experience if the students were to encounter an engineering ethical dilemma. The students also reported participating in a number of co-curricular experiences, but their impacts on the ethical development of the students were less clear. A national study of capstone design [24] with 506 respondents included 22 responses from computer engineering, but did not report results by different disciplines; among all responses, engineering ethics was included within the lecture in 69% of the courses, individual assignments by 30% of the courses, and as part of the team project in 45% of the courses; engineering ethics was not covered in only 12% of the capstone design courses. Related topics such as intellectual property and sustainability were also included in some manner in a majority of the courses.

The impacts of co-curricular experiences on engineering students' ethical development were also studied in focus groups by Burt et al. [25], but it was unclear if any of the students who participated were majoring in computer or software engineering. Undergraduate research experiences are a specific example of co-curricular experiences for computing students that sometimes include ethics education [26-27].

In the present study, an effort was made to characterize the microethics and macroethics education of engineering and computing students in the United States, using a survey of faculty members. Given both the related and unique elements of computing disciplines compared to engineering disciplines, it was of interest to characterize similarities and differences in the ethics education associated with these disciplines.

II. Research Questions

RQ1. What ESI topics are taught to computing students in courses? Does this vary by the computing affiliation of the instructor? How does this compare to the ESI topics taught to other engineering disciplines?

RQ2. What types of courses for computing students include ESI topics? Are these similar to the course types including ESI that are taught to engineering students?

RQ3. What teaching and assessment methods are used to teach ESI topics in courses for computing students and other engineering disciplines?

RQ4. What ESI topics and teaching methods are included in co-curricular settings for computing students? Are these similar to or different than ESI topics in co-curricular settings for other engineering majors?

RQ5. What are faculty perceptions of the sufficiency of ESI education of computing students, as compared as other engineering disciplines?

III. Methods

This research was reviewed and approved by an Institutional Review Board for human subjects research. Surveys were developed to solicit information on where and how faculty teach engineering and computing students about ethical and societal issues (ESI) in both co-curricular and curricular settings [28]. Computing disciplines were explicitly invited to participate in the survey via three primary avenues. A list of ACM and ACM-W student chapters in the U.S. were located online and 292 faculty advisers contacted. Among this group, 59 responses (a 20% response rate) were received. A similar process was used for Upsilon Pi Epsilon, the honor society for computing, with 247 student chapters, from which 114 contacts were compiled and 23 responses received (20%). Faculty mentors for IEEE university chapters and other professional groups were contacted in a similar manner [28]. Authors of papers on ethics education in computing were also directly solicited; 73 from the Special Interest Group on Computer Science Education (SIGCSE) Technical Symposium with 17 responses (23%). More generally, invitations were emailed out to the members of a variety of divisions of the American Society for Engineering Education, including Educational Research & Methods, Engineering Ethics, Community Engagement, and the Liberal Education/Engineering & Society. Overall, there were 1448 respondents who completed at least 30% of the survey was completed, including 1242 who finished the survey. Individuals could skip any of the questions on the survey, so the number of responses to each question vary.

In demographic questions at the end of the survey, individuals were asked to indicate the disciplines where they teach ESI, indicating as many choices as were relevant. For the purposes of analysis we wanted to identify individuals who taught primarily computing students. This was done by identifying respondents who solely indicated teaching computing (n=139), as well as those who also noted only electrical, first-year, general, or other (such as informatics, calculus) and were housed a computing department (49 additional responses). Among these 188 responses, 16% also taught electrical engineering. These computing responses were compared to those who did not teach computing students but did indicate other disciplines that they taught (1161 responses). The engineering disciplines taught by these respondents included civil (23%), mechanical (23%), chemical (11%), electrical (11%), biomedical (10%), and others. Fifty responses were excluded because they taught computing and another main engineering disciplines such as computer and civil engineering, and 49 responses did not indicate any disciplines they taught.

Given our desire to explore different sub-areas of computing, the departmental and school/division of the departments were located from online information. These were then grouped into two categories: engineering (the department was co-located in a college with engineering majors, n=111) and non-engineering (a separate school or college of computing/information sciences, n=17; co-located with general college of sciences and/or arts, n=34; small enough college that departments not grouped, n=14; and computing in a college/school with business majors, n=10). The majority of the computing programs represented by the respondents in the survey offered multiple degree types through the same program, such as both a BS in Computer Science (often ABET CAC accredited) and a BA in Computer Science (not accredited). Some programs also offered a BS in Computer Engineering or BS in Software Engineering (often ABET EAC accredited). Among the 188 computing respondents there were 86 associated with ABET CAC-accredited degrees and 81 associated with ABET EAC degrees (in CE, CSE, and/or SE).

The demographic characteristics of the respondents in each group are noted in Table I. Note that the same institution could appear in multiple categories, due to respondents from computer engineering, computer science (outside engineering), and other non-CS engineering disciplines (such as mechanical or civil). A larger percentage of the computing faculty taught at Bachelor's and Master's institutions compared to other engineering disciplines. Respondents encompassed all academic ranks. The percentage of female respondents among the computing faculty was 34% overall and 31% among tenured/tenure-track (T/TT) faculty; this is significantly higher than the reported 15% women among T/TT faculty in CS departments [29] and 17% women among T/TT faculty in CS inside engineering [30].

A question on the survey asked whether individuals would be interested in participating in follow-up interviews. From among the 229 individuals indicating an interest, 52 were invited to participate in interviews, and 37 interviews completed. Semi-structured interviews 30-60 minutes in duration were conducted via Skype or phone; one international respondent emailed a response to the interview questions. Among the interviewees, six were faculty in electrical and computer engineering (two authored books related to technology/society, another published extensively on ethics education), one taught ethics to many disciplines including CS (with a BS in genetics and advanced degrees in Ethics and Social Theory), and one taught ethics for CS from a personal background in psychology. Summaries of the interviews were checked by the interviewees to confirm accuracy. Content from the interviews is integrated into the manuscript to lend richness to the survey results.

TABLE I. DEMOGRAPHICS OF SURVEY RESPONDENTS

Characteristic	% Computing (n=188)	% Non-CS Engrg (n=1161)	% Computing in Engrg (n=111)	% Computing outside Engrg (n=77)
Unique Institutions (n)	*(159)*	*(350)*	*(95)*	*(70)*
Highest degree at Institution				
Associates	1	0.4	0	3
Bachelor's	14	6	7	23
Master's	19	12	14	26
Doctorate	66	82	78	48
Institutional Control				
Public	68	73	72	61
Private	32	27	28	39
Academic Rank				
Full professor	39	34	37	43
Associate professor	27	28	29	25
Assistant professor	15	18	15	14
Instructor/full time nonTT	13	11	14	12
Other	6	9	5	7
Additional roles				
Department head or chair	10	8	5	18
Director of center, program	11	16	11	10
ABET assessment coord.	10	8	12	7
Others	12	19	12	12
Gender	(n=187)	(n=1159)	(n=111)	(n=76)
Male	63	66	62	63
Female	34	32	33	34
Prefer not to say	4	3	5	3

IV. RESULTS AND DISCUSSION

A. RQ1. ESI Topics integrated into Courses

Table II shows the percentage of 18 ESI topics taught by those who indicated teaching one or more of the topics in their courses. These results from individuals from computing programs differ substantially from the earlier study of entire curriculum coverage [18]; across entire curricula, 87-93% indicated coverage of professional & ethical responsibilities, social context, risk & liabilities, privacy & civil liberties; 49% included philosophical frameworks. The earlier results reflected that ESI topics were taught across multiple courses by multiple individuals.

Comparing computing versus other engineering disciplines, there were more differences than similarities. Three ESI topics (privacy, ethical theories, war) and "other" were taught more commonly to computing than other engineering students; seven ESI topics were more commonly taught in courses for engineering students than computing students (environmental protection, sustainability, engineering decisions under uncertainty, safety, engineering codes of ethics, engineering & poverty, and bioethics). The number of respondents not including any ESI topics in their courses was higher among computing faculty than other engineering disciplines (17% versus 11%). Comparing just the computing programs associated with engineering (c-E) to other engineering disciplines, c-E more commonly included three ESI topics and less commonly included five topics.

TABLE II. ESI TOPICS IN COURSES

ESI Topic	% Computing (n=154)[1]	% Non-CS Engrg (n=994)	% Computing in Engrg (n=93)[2]	% Computing outside Engrg (n=60)[3]
Professional practice issues	64	63	61	67
Societal impacts of technology	62	56	63	58
Privacy and civil liberties	48**	9	41**	58*
Ethical failures / disasters	44	46	45	42
Risk and liabilities	41	37	40	42
Engineering codes of ethics	40*	50	55	15**
Ethics in design projects	40	42	48	25*
Responsible conduct of research	37	34	39	33
Ethical theories	36**	21	35*	37
Safety	35**	54	41*	25
Eng decisions under uncertainty	33**	54	43*	17**
Social justice	23	18	20	27
Sustainability	21**	52	19**	22
War, peace, military appl.	17*	8	16*	17
Other	16*	8	16	13
Environmental protection issues	8**	41	10**	3
Engineering and poverty	8*	18	10	3
Nanotechnology	5	4	5	5
Bioethics	1**	9	2*	0
Average # ESI topics	*5.8*	*6.2*	*6.1*	*5.2*
No topics	17* (n=31)	11 (n=118)	15 (n=17)	19 (n=14)

[1] compared to non-CS engineering; [2] compared to non-CS engineering, [3] compared to computing in engineering; * $p \leq 0.05$, ** $p \leq 0.001$

The other topics written in for computing instructors were: intellectual property, IP (n=8), computing/IT ethics (n=4), cybersecurity (n=3), diversity (n=2), digital divide, technology for aging, universal usability, value sensitive design, ethical computer games, HIPPA, sociological theories of technology, ethical leadership, free speech, black hat vs. white hat hacking, litigation alleging fraud/negligence, plagiarism and professional academic honesty, big data, net neutrality, workplace politics, ethics in policy making, ethics and social media, "stability of future society given current political, economic, social, and engineering decisions", and life cycle design . The IP topics could have been anticipated; 89% of the programs in Spradling's 2005 survey indicated inclusion of IP topics [18]. The higher number of other topics written-in from the computing respondents perhaps reflects the bias of the survey designers (none from computing engineering disciplines) and the small number of computing faculty included in the pilot testing of the survey (4 indicated teach computing students out of 29 responses).

Comparing computing programs associated with engineering to those not associated with engineering, there were differences in the extent that 4 ESI topics were taught in courses. Computing programs in engineering included more on the engineering codes of ethics, ethics in design, and engineering decisions under uncertainty; computing programs not associated with engineering more commonly included privacy and civil liberties. Thus, it was found that computing programs in engineering were more similar to nonE computing programs than other engineering disciplines as a whole.

B. RQ2. Courses with ESI

The types of courses that instructors reported as including ESI were generally similar between computing and other engineering disciplines (Table III); somewhat more of the computing instructors taught a full course on ethics. Individuals at 40 of the 132 institutions, 30%, indicated that they taught a full course on ethics (n=16) and/or a professional issues course (n=31); this is lower than the 51% and 70% of programs that included a standalone course on ESI topics in the 2005 studies [17-18], likely due to differences in how individuals were invited to participate in the survey. For example, in the current study an individual who mentors ACM and does not teach a full course on ESI may have responded to the survey, while an individual from the same program who teaches a full course on ethics did not respond to the survey. Comparing computing inside and outside of engineering, more differences in course types were evident. Respondents from computing programs outside of engineering were more likely to teach ESI in professional issues courses, graduate level courses, first-year introductory courses, and humanities/social science courses.

Table III. Course types where Faculty teach ESI Topics

Course Types	% Computing (n=154)	% Non-CS Engrg (n= 994)	% Comput in Engrg (n=93)	% Comput outside Engrg (n=60)	% comp selected as "most effective" course
Sophomore or junior core engrg science or engrg	38	40	39	35	50
Senior capstone design	35	41	39	28	27
Graduate-level (any type)^	29	32	20	36*	65
Design-focused soph, jr, sr	27	34	28	25	27
First year introductory	26	30	25	19*	24
Professional issues	20	16	12	33*	38
Other	16	11	18	12	47
Full crs on engineering ethics (any level)	10*	6	12	8	83
First year design-focused	8	13	10	5	27
Humanities / social science	7	9	3	13*	13
Average number of course types	*2.2*	*2.3*	*2.0*	*2.4*	

^ percentage among individuals from institutions with graduate programs; * $p \leq 0.05$, ** $p \leq 0.001$

Individuals were asked to describe the one course where they most effectively taught ESI and 141 individuals who taught computing students responded. There were 85 respondents who taught multiple course types that included ESI and described a course, among that group the largest percentage described their full ethics course (83%) or graduate-level course (65%) while the other course types appeared to be perceived as less effective; see the rightmost column of Table III for the percentages for other course types. Example titles of the full courses on ethics were:

- Social and Professional Issues in Computer Science

- Ethical Issues in Computing
- Technology, Public Policy and Urban Society

Course title examples for the graduate level courses were:

- Ethical Issues in Information Assurance and Security
- Software Requirements
- Advanced Topics in Information Security

Examples of sophomore or junior level engineering science courses described by computing faculty include:

- Introduction to Programming 1
- Computing Programming II
- Computer Architecture
- Database Systems
- Cryptography
- Object-Oriented Programming
- Systems and Network Administration

Titles of the design-focused courses in sophomore to senior year were:

- Software Engineering
- Large Scale Software Development
- Robotics for Humanity

Among the eight interviews associated with computing faculty or those who taught computing students, full courses on Engineering or Software Ethics were described by four individuals, two described full courses on Technology and Society, one individual described capstone design, and one described an elective service-learning design course. Three of the four Engineering or Software Ethics courses that were detailed in the interviews were required at their respective institutions and one of the two Technology and Society courses was compulsory. Three of the interviewees discussed the implications and tradeoffs of teaching ESI in required versus elective courses. The instructor with an ethics and social theory background who teaches a required graduate course in software ethics noted that making a course mandatory reflects its importance and reaches the broadest audience. However, when students self-select into a course, they tend to be more engaged. Another interviewee, who has taught both required and elective courses on ethics, commented when students were filling a requirement and "had to be there" their "motivation was much lower." These comments raise considerations about the most effective courses in which to teach ESI and provide insight into the advantages and disadvantages of electives versus requirements.

C. *RQ3. Instruction Methods for ESI*

With the course individuals indicated they most successfully taught students about ESI, a median of five different methods were used to teach ESI topics. The utilization of a range of teaching methods may be a good method to encompass all of the elements within the 4DDD [3]. For example, in-class discussion primarily maps to the social domain, lectures to the cognitive domain, reflection to the affective domain, and design or service-learning to the psychomotor domain. The ESI teaching methods used were generally similar for all respondents (Table IV), with the exception of more use of engineering design and project based learning in engineering vs. computing, and more use of humanist readings and other methods in computing. There was only a single difference between computing respondents affiliated with engineering, with higher use of engineering design compared to CS outside of engineering.

Table IV. ESI Teaching Methods in Courses

ESI Teaching Methods	% Computing (n=141)	% Non-CS Engrg (n=946)	% Computing in Engrg (n=86)	% Computing outside Engrg (n=54)
In-class discussion	73	66	71	76
Case studies	68	66	65	76
Lecture	63	65	59	69
Examples of professional scenarios	63	60	65	59
Videos, movie clips	29	27	28	31
Project based learning	28*	39	30	22
In-class debates/role plays	28	21	26	30
Guest lectures	26	31	24	28
Reflection	24	25	26	22
Engineering design	21**	45	31	2**
Humanist readings	17*	8	15	19
Think-pair-share	13	14	15	11
Other	12*	7	14	9
Moral exemplars	11	8	13	7
Problem solving heuristics	11	14	10	11
Service-learning	9	14	8	7
Average number of methods	*5.0*	*5.2*	*5.0*	*4.8*
Median number of methods	*5*	*5*	*5*	*4*

* $p \leq 0.05$, ** $p \leq 0.001$

Other teaching methods listed by computing instructors included:

- Current news stories (3)
- Student presentations (2)
- Position papers (2)
- Student research paper (2)
- On-line discussions
- Online lectures before class
- Online module based on textbk
- CITI training
- Read papers on morality of crypto research
- Fiction readings as case studies (2)
- Writing analyses of ethical issues
- Participate in professional meeting or conference
- Design studios
- Develop, describe own moral theory

Within the courses described by those interviewed, case studies were used in all of the courses. Reflection, discussion, and role-playing were also common. An instructor who described an engineering ethics course in the interview noted that active learning pedagogies were "much more effective than just listening." He noted that educators "need to help them [students] understand that professionals have special responsibilities" to the public in terms of ethics. Having students participate in debates, discussions, and role-playing activities "catches their attention" and allows them to actively engage in the material. This resonates with the learning motivation cycle in the 4DDD model [3], particularly triggering students' interests and values.

The survey also asked faculty to report the methods that they used to assess students' knowledge of ESI in their courses. For computing instructors, a median of two assessment methods were used; 16% did not assess ESI learning outcomes. The most commonly used assessment methods were: individual reflective essays (43%); individual homework assignment, essay, and/or papers that are graded with a rubric (40%); test and/or quiz questions (38%), and group-based written assignments (28%). There were not statistically significant differences in the ESI assessment methods used by engineering instructors outside computing (data not shown).

One course described in an interview included 60% of the course grade based on a project where teams of about three students serve as consultants examining the ethical considerations of software for real clients. In this junior-level Ethical Issues in Software Design course, students apply human computer interaction knowledge to the software the client is developing. The project affords the opportunity to develop skills such as conducting talk aloud protocols, focus groups, and cognitive walkthroughs while also learning to make ethical arguments, interact with professionals, and fulfill their duty to clients. Students apply these skills and their knowledge of moral reasoning to examine ethical issues that might arise with the software that the client had not considered. Students develop a report and give a half hour presentation to the class and client. The clients evaluate the projects and give feedback, which factors into the students' grades. The projects provide a real application of the course topics since issues such as privacy, IP, equal access, and data security are discussed in class and are organically integrated into the projects. The experience helps students understand that ethical issues are inherent to software that is embedded in sociotechnical systems, and empowers the students to understand the extent to which they have control over the implications of their work.

D. RQ4. Co-curricular Settings

Co-curricular settings were previously identified as activities that increase students' ethical reasoning [2]. Because co-curricular activities are self-selected by students, this autonomy is likely to increase their motivation for learning in these settings. The survey asked respondents which ESI topics they taught in up to two different co-curricular activities that they mentored; results are summarized in Table V. For individuals who taught computing students, the types of co-curricular activities described were primarily professional societies (such as ACM, 45%), research (23%), honor societies (such as Upsilon Pi Epsilon, 16%), other (12%), design competitions (3%), and engineering service groups (1%). The co-curricular activities mentored by computing faculty that included ESI topics contained a median of three topics; lower than co-curricular activities for other engineering disciplines that included a median of four topics. In addition, a higher percentage of the co-curricular activities for computing students included no topics related to ESI (20% versus 8%). However, the types of co-curricular activities described by other engineering disciplines differed (42% professional societies, 16% research, 14% honor societies, 12% student design competitions, 11% engineering service groups such as Engineers Without Borders, 5% other). Of the 18 specific ESI topics, only one (privacy and civil liberties) was more common in co-curricular activities mentored by individuals who teach computing students; nine topics were more common in co-curricular activities for other engineering disciplines. "Other" ESI topics were also more common in the co-curricular activities for computing students; these included: diversity/equality/bias (n=9), IP, ethical hacking, and cybersecurity.

Table V. ESI topics included by faculty in co-curricular activities

ESI Topic	% Computing (n=134)	% Non-CS Engrg (n=1118)	% ACM (n=39)	% other prof societies (n=511)
Professional practice issues	63	66	77	79
Societal impacts of eng & technol	41	49	36	50
Responsible conduct of research	34	29	13	17
Privacy and civil liberties	24**	5	36**	3
Engineering codes of ethics	23*	32	23	37
Safety	18**	53	13**	44
Eng decisions under uncertainty	16**	42	18*	35
Risk and liabilities	16**	31	8*	24
Ethics in design projects	16*	25	15	21
Sustainability	15**	43	5**	41
Ethical failures / disasters	13	19	10	20
Other	13*	6	18*	7
Social justice	11	14	15	13
Ethical theories	6	5	5	5
Environmental protection issues	5**	32	0**	31
Engineering and poverty	4**	20	5	12
War, peace, military appls	4	5	0	7
Nanotechnology	2	3	0	2
Bioethics	1*	5	0	1
Average # ESI topics	*3.3*	*4.8*	*3.0*	*4.5*
Median # ESI topics	*3*	*4*	*2*	*4*
No topics	20** (n=33)	8 (n=92)	24** (n=12)	9 (n=48)

* $p \leq 0.05$, ** $p \leq 0.001$

Looking specifically at ACM in comparison to other disciplinary professional societies (such as ASCE, IEEE, etc.), similar trends were found (Table V). Only privacy and civil liberties and "other" ESI topics were included in ACM more than other disciplinary professional societies; six other topics were less frequently found in ACM. A higher percentage of ACM responses compared to other professional societies did not include any topics related to ESI

The ways instructors believed students participating in ACM learned about ESI were primarily: lectures, presentations, and/or guest speakers (78%), discussions (61%), working with a community (41%), design projects (15%), and other (2%). Elaborating further on these activities, write-in descriptions included:

- Professionals from the field share the ethical situations they have faced and how they have responded. Students who have had internships and co-ops also share the ethical situations they have experienced.
- By discussing current events.
- Our students interact with k12 students from our community.
- Hackathons for non profit organizations.
- By direct contact with communities that have a deficit in the availability of technology and education of technology.
- A hosted event, such as Hour of Code or a FIRST Lego League competition.

E. RQ5. Sufficiency of ESI Instruction

Among computing educators, 32% believed that undergraduate students in their program received sufficient education about ESI, compared to 23% sufficiency for graduate students. There were not significant differences in the perceptions of ESI educational sufficiency between computing versus other engineering disciplines at either the undergraduate or graduate levels; Table VI. There were also no significant differences in the ESI educational sufficiency opinions of individuals associated with computing in engineering versus computing outside engineering (data not shown).

Table VI. Faculty Opinions of Sufficiency of ESI Education

Do students in your program receive sufficient education on the societal impacts of technology and ethical issues?	Ugrad Comp	Ugrad other engrg	Grad Comp	Grad other engrg
(N with opinion, not inc. unsure)	*(150)*	*(943)*	*(110)*	*(745)*
1. Yes, but too much; the time could be better spent on other topics	1	1	2	1
2. Yes, a sufficient amount	31	31	21	17
3. A sufficient amount of ethics, but insufficient on the broader impacts of technology	13	16	6	10
4. A sufficient amount on the broader impacts of technology, but not enough ethics	12	12	5	11
5. No, not enough	43	39	66	61
Unsure / not applicable (n)	*(20)*	*(140)*	*(58)*	*(329)*
% of all responses	*12*	*13*	*35*	*31*

However, there were differences in where computing and non-computing engineering faculty believed undergraduate students in their program learned about ESI; Table VII. For computing, there were an average of 2.6 curricular and/or co-curricular settings, compared to 3.5 among non-computing engineering faculty. Computing faculty were less likely to believe their students learned about ESI in a senior capstone design course, first-year introductory course, design focused course in the sophomore-senior year, and co-curricular settings (perhaps due to the language used in the survey that referred to these as "engineering" co-curricular groups).

Table VII. Settings where Faculty Believe Undergraduate Students learn about ESI

Course or co-curricular setting	% computing *(n=153)*	% other engrg *(n=978)*	% computing in engrg *(n=91)*	% comput outside engrg *(n=53)*
Senior capstone design course	52*	65	58	38*
Soph-Jr Eng/Eng science crs	40	37	34	45
First-year introductory course	36*	46	33	38
Professional issues course	24	28	26	15
Humanities/social science crs	26	33	19	38*
Design-focused course in soph-senior year	22*	35	19	30
Full course on ethics	22	17	26	13^
First-year design focused crs	8**	22	8	8
Co-curricular professional society (e.g. AGC, IEEE)	10**	28	13	8
Co-curricular engineering service society (e.g. EWB)	7**	28	11	2^
Other courses and/or co-curricular activities	14	10	10	23*
Average number of course & co-curricular types	*2.6*	*3.5*	*2.6*	*2.6*

^ p 0.05 to 0.10; * p≤0.05, ** p≤0.001

Differences were also noted between computing inside/outside of engineering in the settings where faculty believed undergraduate students learned about ESI. Fewer of the computing programs outside engineering included ESI in a senior capstone design course and more included these topics in humanities/social science courses. In addition, the higher "other" category for computing faculty outside engineering may indicate that the language used in the survey was a poor fit to describe course and co-curricular types for computing. The survey was only piloted with engineering and computing faculty associated with engineering, perhaps leading to this poor fit to non-engineering affiliated computing programs.

Among individuals who believed undergraduate computing students in their program learned about ESI in a full course on ethics, 47% believed that students received sufficient education on ESI (higher than the 32% overall). Among those who believed computing students in their program learned about ESI in two or less (n=86) versus six or more settings (n=7), 30% versus 57%, respectively, believed that students received sufficient education on ESI. Thus, there appears to be both quality and quantity factors that impact faculty perceptions of ESI educational sufficiency. The most significant factor, however, may be differences in what individual faculty consider "sufficient" education. For example, there were three T/TT faculty respondents from the same program; one rated undergraduate ESI education as 2 = "sufficient" while the other two rated it as 5 believing there was not enough broader impacts or ethics. In the write-in box, one of the respondents who classified the undergraduate education as insufficient wrote:

> "I think the topics are raised superficially in many places. We have no assurance that they learn anything anywhere. Multiple-false exams, short-essay questions, and political-correctness surveys look good to bureaucrats as assessment instruments but they don't address the evolution of the student's judgment or concern or their ability to consider multiple views and actually apply any kind of ethical reasoning. I think the depth of assessment has declined as 'success' on these topics has become a tickbox requirement."

Other open-ended survey responses reiterated that ethics education was generally insufficient, although opinions varied on whether "this material should be in ALL of the courses, though briefly" (n=5) or "it is better to teach ethics in a dedicated course than to try to integrate it throughout the curriculum." (n=5) Further, some faculty contrasted computing education inside and outside of engineering. For example:

> "I think it is important, but I almost feel that in schools of information (vs engineering schools) we focus too much on these topics. In particular, there is a strong emphasis on activism, and I would like to see a stronger emphasis on skepticism. People feel they are ethical if they are anti-capitalist or anti-establishment, and this isn't what I would consider appropriate ethical training."

Among the interviewees, a variety of perspectives were evident. One instructor discussed integrating ethical issues into all of the courses that he taught, so that students understand their role in a social ecosystem and the social context in which engineers operate to help students bridge the technical-social gap. He was a faculty member with a background in electrical engineering who described a required 1-credit Ethics and Professionalism course that he taught to seniors in computer engineering and three other engineering majors at a large Master's institution. He also noted that the institution as a whole was very supportive of ethics education, which fit with its religious-affiliation and overall worldview.

In contrast, another faculty member in Electrical and Computer Engineering noted that their curriculum did not include a full engineering ethics course, but that the first-year introductory course included an ethics module along with integration of ethics into the senior design sequence. There were difficulties integrating ethics across the curriculum. This individual noted that a subset of the faculty were narrowly focused on technical content and developing technically competent students, others felt unqualified and unprepared to teach ethics.

V. Limitations

The research results are limited to those who chose to respond to the survey. These individuals may or may not be representative of computing and engineering faculty overall. It is likely that those who teach ESI or have an interest in ESI would be more likely to respond to the survey. Because the majority of the survey recruitment methods targeted engineering, faculty in computer science departments outside of engineering may be under-represented among the data set. Faculty perceptions of teaching and what students learn may be different. Some may have greater knowledge on the undergraduate program as a whole, such as a department chair or ABET assessment coordinator, while others may be more/less familiar with the graduate curriculum. The nuances of the five different types of computing degrees, degrees that are/are not ABET-accredited, and Bachelor of Arts versus Bachelor of Science degrees were not explored. This would be an area for further research.

VI. Implications and Conclusions

The survey results indicate distinct differences in what and how computing instructors teach microethics and macroethics compared to other engineering disciplines. However, the majority of both computing and engineering programs are seen as providing insufficient ESI education. The greater deficiency in graduate programs is likely due to the lack of pressure from accreditation requirements.

This study revealed a number of different types of both courses and co-curricular settings where faculty teach computing students about ESI. Given the wealth of examples across a broad range of courses, it is clear that ESI topics could be integrated into any course. This frequent integration into many courses across a range of topics, even if only very briefly, might help communicate to students the importance of these considerations in numerous contexts. However, to leverage students' ethical reasoning abilities, deeper discussions and assignments will be needed. Instructional methods that embrace a range of learning domains and attend to the motivational cycle for learning as proposed in Vanasupa's 4DDD model [3] are likely to be more effective in this regard. If computing and engineering instructors feel unprepared to incorporate these richer and deeper teaching strategies for ESI, professional development and team teaching with philosophy faculty are ideas to consider.

Given the broad impacts of technology on society and the environment, it is important that computing students are trained to think critically and deeply about ESI issues. Students need to believe that these issues are important and part of their job, going well beyond simple microethical considerations to comply with codes of ethics. This also extends beyond cognitive domain outcomes to embrace the affective domain where individuals value ethical actions and act in accordance with this set of values. Future professionals cannot be expected to embrace a broad sense of social responsibility and behave accordingly if their education lacked these elements.

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