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Ethics and Societal Impacts in the Education of Chemical Engineering Undergraduate and Graduate Students

Dr. Angela R Bielefeldt, University of Colorado, Boulder

Angela Bielefeldt is a professor at the University of Colorado Boulder in the Department of Civil, Environmental, and Architectural Engineering (CEAE). She has served as the ABET assessment coordinator in her department since 2008. Professor Bielefeldt's research interests in engineering education include service-learning, sustainable engineering, social responsibility, ethics, and diversity.

Ms. Madeline Polmear, University of Colorado, Boulder

Madeline Polmear is a PhD student in the Department of Civil, Environmental, and Architectural Engineering at the University of Colorado, Boulder. Her research interests include ethics education and the societal impacts of engineering and technology.

Dr. Chris Swan, Tufts University

Chris Swan is an associate professor in the Civil and Environmental Engineering department at Tufts University. He has additional appointments in the Jonathan M. Tisch College of Civic Life and the Center for Engineering Education and Outreach at Tufts. His current engineering education research interests focus on community engagement, service-based projects and examining whether an entrepreneurial mindset can be used to further engineering education innovations. He also does research on the development of reuse strategies for waste materials.

Dr. Daniel Knight, University of Colorado, Boulder

Daniel W. Knight is the Program Assessment and Research Associate at Design Center (DC) Colorado in CU's Department of Mechanical Engineering at the College of Engineering and Applied Science. He holds a B.A. in psychology from Louisiana State University, an M.S. degree in industrial/organizational psychology and a Ph.D. degree in education, both from the University of Tennessee. Dr. Knight's research interests are in the areas of retention, program evaluation and teamwork practices in engineering education. His current duties include assessment, team development and education research for DC Colorado's hands-on initiatives.

Dr. Nathan E. Canney,

Dr. Canney's research focuses on engineering education, specifically the development of social responsibility in engineering students. Other areas of interest include ethics, service learning, and sustainability education. Dr. Canney received bachelors degrees in Civil Engineering and Mathematics from Seattle University, a masters in Civil Engineering from Stanford University with an emphasis on structural engineering, and a PhD in Civil Engineering from the University of Colorado Boulder.

Ethics and Societal Impacts Education of Chemical Engineering Undergraduate and Graduate Students: Results of a National Survey

Abstract
The new ABET EAC accreditation outcomes recognize the importance of educating students about their ethical and professional responsibilities, and how these relate to the impact of engineering in societal and environmental contexts. This research explored how the educators of chemical engineering students viewed the sufficiency of education on ethics and societal impacts (ESI), as well as their own teaching practices for ESI. Two online surveys gathered feedback from chemical engineering instructors, resulting in 107 respondents representing 76 institutions. A large percentage of the chemical engineering respondents felt that undergraduate education was deficient on ethics (50%) and broader impacts (46%). Graduate student ESI education was perceived to be even weaker; 76% rated ethics education insufficient and 74% rated broader impacts education insufficient. At the median, chemical engineering faculty identified three different types of courses where they believed undergraduate students in their program learned about ESI, most commonly capstone design (72%). Over half of the chemical engineering instructors reported teaching safety, professional practice issues, engineering decisions under uncertainty, environmental protection issues, sustainability, ethical failures, and the societal impacts of technology in their courses. The survey and follow-up interviews with three chemical engineering faculty members provide more specific information on the teaching of ESI in first-year introductory courses, core engineering science courses, and senior capstone design. The ESI teaching and assessment practices used in these different types of chemical engineering courses varied. The survey respondents also reported examples of teaching students about ESI topics in co-curricular settings such as professional societies (e.g. the American Institute of Chemical Engineers), undergraduate research (REU sites), honor societies (e.g. Omega Chi Epsilon), and design competitions. The results provide examples to chemical engineering instructors on integrating ESI into any teaching setting. Micro-insertion of ESI into core engineering courses across the curriculum as well as deeper and more critical exploration in one or two targeted courses may provide a combination that yields appropriate student education on ESI.

Introduction

Chemical engineering students, like all engineers, need to be educated about ethics and societal impacts (ESI), in order to prepare them for their careers. Accreditation requires this knowledge, with the new ABET criteria 3 outcome (4) acknowledging the interconnected elements of ethics and societal impacts: "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts" [1]. In addition, the Chemical Engineers Body of Knowledge describes the specific affective and cognitive domain outcomes related to ESI that are desirable [2]. Across engineering as a whole, some individuals advocate an ethics across the curriculum approach as most effective for developing students' ethical reasoning abilities [3-7]. This includes thoughtful design of the ethics education of students across multiple courses. The design is intentional, crossing multiple topics as well as depth of cognitive and affective outcomes for ethical knowledge, values, and behaviors. This may include micro-insertion, which are a few small ethics issues integrated into class for a few minutes on multiple occasions during an academic term [8-9]. Vanasupa et al. [10] proposed a four-domain development diagram for effective ethics education that crosses cognitive, affective, psychomotor, and social domains of learning, driven by a motivational cycle that includes autonomy and value. Studies have also found that engineering co-curricular activities can contribute to students' ethics education [11-13].

A number of papers have been published that provide examples of ethics education in chemical engineering courses [14-21]. Surveys of how key chemical engineering courses are taught have determined that within material and energy balances courses, ~44% include ethics, ~44% include sustainability, and ~62% include safety/health/environment [22]. Within capstone design courses, the percentage that included various ESI topics were: 37% ethics, 16% sustainability/life-cycle analysis, and a breadth of safety issues [23]. However, a thorough synthesis of ESI educational practices and perceptions within chemical engineering is lacking.

Research Questions
Four broad research questions are explored in this paper.

RQ1. To what extent do chemical engineering faculty believe that undergraduate and graduate students in their program receive sufficient education on ethics and/or societal impact issues?

RQ2. To what extent do chemical engineering faculty believe that undergraduate students in their program learn about ESI in different course types? 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?

RQ3. What ESI topics, teaching methods, and assessment methods are used in various types of courses for chemical engineering students: (a) first-year, (b) sophomore/junior engineering science/engineering, (c) capstone design, (d) undergraduate electives, (e) graduate courses.

RQ4. To what extent do chemical engineering faculty educate students about ESI in co-curricular settings? Do ESI topics and educational approaches vary among different types of co-curricular settings?

Methodology
Two online surveys were developed to determine the what, where, and how of ESI education in engineering: one focused on courses (the curricular survey) and one focused on co-curricular settings (the co-curricular survey). Chemical engineering faculty were directly invited to participate in the survey as mentors for relevant co-curricular groups (AIChE and Omega Chi Epsilon). Otherwise, chemical engineering faculty were generally included along with other engineering educators in email invitations sent to lists from the American Society for Engineering Education, authors of papers on ethics, and principal investigators for Research Experiences for Undergraduates (REU) sites. Further details on the survey development, administration, and questions have been published [24-25]. Individuals could skip any questions on the survey that they desired, so the response numbers for particular survey questions vary.

The survey results were sorted to identify the respondents who taught chemical engineering students. There were 80 individuals who taught only chemical engineering students and another 27 taught both chemical engineering students and related area(s) (biomedical, n=12; biological, n=6; environmental, n=7; materials, n=5; petroleum, n=3; plastics, n=2; paper=1). These two groups were combined to represent chemical engineering respondents, n=107. These individuals represented 76 different institutions, including 72 that award ABET EAC-accredited bachelor's degrees in chemical engineering and two international. The ranks of these chemical engineering instructors were 36% full professors, 33% associate professors, 21% assistant professors, and 8% full-time instructors. Additional positions held by these respondents included 20% directors of program or center, 16% ABET assessment coordinators, and 9% department chairs or heads. The chemical engineering respondents were also 67% male and 33% female. A group of 36 survey respondents taught chemical engineering students in addition to a wide array of other engineering disciplines (including mechanical, civil, electrical, etc.); these responses were excluded from the analysis due to confounding factors. There were 1252 respondents who taught engineering disciplines outside of chemical engineering. The responses from this group were compared to the chemical engineering faculty for ESI sufficiency ratings; chi-squared tests were used to evaluate significant differences.

The survey respondents were asked to indicate if they would be willing to participate in a follow-up interview. Among 37 semi-structured interviews that were conducted, three were with chemical engineering faculty. Interview methods have been published [26]. Information from the interviews is included to provide richness and depth to the results.

Results and Discussion

RQ1: Sufficiency of ESI Education

A large percentage of the chemical engineering faculty felt that education of the undergraduate students in their program was deficient on ethics (50%) and broader impacts (46%) (Table 1); this was somewhat better than the perceptions of other engineering disciplines about the sufficiency of ESI education, but not statistically different (chi-test p=0.07). Those rating undergraduate ESI education as sufficient encompassed 28 different institutions, including 7 cases where another individual from the same institution felt that the undergraduate education was lacking in either ethics and/or broader impacts. This result could be attributed to varying perceptions of sufficiency or differing awareness of ethics content within the program.

Table 1. Do students in your program receive sufficient education on ethics and broader impacts?

Response	Chemical, %		Other Engrg, %	
	Undergrad (n=96)[a]	Graduate (n=83)[b]	Undergrad (n=1006)	Graduate (n=777)
1. Yes, but too much; the time could be better spent on other topics	0	1	1	1
2. Yes, a sufficient amount	35	14	30	18
3. A sufficient amount of ethics, but insufficient on the broader impacts of technology	15	8	17	9
4. A sufficient amount on the broader impacts of technology, but not enough ethics	19	10	11	10
5. No, not enough	31	66	41	62

[a] Unsure was also a response category, but these responses were not included in the percentages; chemical engineering undergraduate, n=6

[b] Unsure/not applicable was also a response category (since some respondents are at programs that do not award graduate degrees), but these responses were not included in the percentages; chemical engineering graduate, n=17

Graduate student ESI education was perceived to be weaker than undergraduate ESI education. Among chemical engineering faculty, 76% rated the ethics education insufficient and 74% rated broader impacts education insufficient; other disciplines had similarly poor ratings of the sufficiency of graduate student education on ESI. Among chemical engineering instructors rating graduate ESI education as sufficient, 10 different institutions were represented; however, another individual at three of those institutions rated graduate education as lacking in either ethics and/or broader impacts.

The results imply that one of more chemical engineering faculty members in the majority of programs believed that ESI education should be improved. Write-in comments from chemical engineering instructors supported their sufficiency ratings. For example, one individual who indicated that their program included a sufficient amount of ESI at both the undergraduate and graduate levels wrote, "These types of broader issues have long been a focus of our engineering college (*name removed*) and Department (Chemical Engineering)." A chemical engineering professor who indicated that both undergraduate and graduate education on ESI were not sufficient wrote, "I strongly believe this aspect of engineering education needs to be enhanced and expanded. Introduction of broader impacts into core engineering courses should be a requirement. As for ethics, due consideration must be given by programs to ensure that students receive sufficient exposure and not just in one course in a single module." Another individual rating both undergraduate and graduate ESI education in their program as not sufficient wrote, "Engineering school pays lip service, assumes they get it in HUM/SS courses."

RQ2: Settings for Undergraduate Student ESI Education
When the chemical engineering faculty indicated where they believed undergraduate students in their program learned about ESI, the most prevalent course type (among 9 options including 'other') was senior capstone design (72%). Other course types believed to include ESI education were: sophomore/junior engineering science/ engineering courses (49%), design-focused courses in sophomore to senior year (non-capstone; 45%), first-year introductory courses (43%), humanities and/or social science courses (35%), first-year design focused courses (26%), professional issues courses (24%), full course on ethics (15%), or "other" courses/co-curricular activities (13%). Course types written in as "other" included: laboratory courses, safety course, inter-professional team project course, and "students are required to take a "Technology in Society" course chosen from a list of ~15 courses that meet this category".

There was a median of three different course types that chemical engineering faculty identified as settings where they believed undergraduate students in their program learned about ESI. Therefore, a number of programs appear to take somewhat of an ESI-across-the-curriculum approach. Among 42 individuals identifying 4 or more course types that include ESI, 35 different institutions were represented. There were 7 individuals who identified six course types and 1 individual who identified 7 course types (representing seven different institutions).

There were differences in the knowledge and/or opinions on what constitutes ESI education within undergraduate programs evident among individuals from the same institution. At one large public research-intensive program with five chemical engineering respondents, the number of identified settings for ESI varied among the raters from two to six. In fact, at fourteen institutions where multiple chemical engineering faculty indicated the settings where they believed undergraduate students in their program learned about ESI, there were only two institutions where there was complete agreement on the course types where ESI education occurred. Thus, individuals may have differing levels of knowledge on how students in their programs are educated on ESI. This may reflect a lack of coordination within programs on teaching ESI. The highest levels of agreement on the course settings for ESI education were among capstone design (86% institutions full agreement on ESI inclusion) and a full course on ethics (86% institutions full agreement, primarily on the lack of a full course on ethics).

There appeared to be some relationship between the perceived sufficiency of ESI education and the number of educational settings including ESI; for those who felt undergraduates received sufficient education on ethics and broader impacts, an average of 4.7 settings were identified versus those who indicated not enough of either ethics and/or broader impacts identified an average of 3.0 settings for ESI education. Using a Spearman rho test, the correlation coefficient between the sufficiency rating and number of course types for ESI education was -0.328 (2-tailed significance 0.001). This means that better sufficiency ratings (1 = too much; 2 = sufficient, 5 = no, not enough) correlated with more course types for ESI instruction.

Given the observed differences in faculty's knowledge on ESI education, variations in the ESI educational sufficiency ratings among chemical engineering faculty at the same institution are not surprising. Among the 14 institutions with multiple chemical engineering faculty respondents, ESI educational sufficiency was rated the same at four. However, at one large, public, research-intensive institution, two chemical engineering faculty agreed on the four settings for ESI education (first-year introductory course, sophomore/junior engineering science/engineering courses, senior capstone design, and HSS courses), but disagreed on their sufficiency ratings (one believing ethics education sufficient but broader impacts deficient, the other both insufficient). Thus, even with similar knowledge on the settings for ESI education within a program, individuals may have differing opinions on what level of ESI education is sufficient.

A number of the write-in comments to the open-ended question regarding broad thoughts on ESI education advocated for an ethics across the curriculum approach, and it seems reasonable that faculty with those beliefs would make this effort in their own courses. One example comment is:

> "Ethics is a very broad topic and I feel, much like it's subtopic of safety, it is best integrated across the curriculum rather than in a single course. In this way students do not compartmentalize ethics into a philosophical and case study / reflective practice but make it part of their everyday professional practice. My hope is formation of this manner will lead them to keep ethics in their post-graduate careers."

Twelve individuals taught ESI in four to eight course types, which may indicate that they integrate ESI into all of the courses that they teach.

RQ3: Course Teaching Practices

In regards to courses, the survey asked individuals which, if any, ESI topics they taught in any of their courses (undergraduate or graduate). A list of 18 topics was provided, plus "other" with write-in space, and none. Among the chemical engineering faculty who responded to this survey question, 97 indicated one or more ESI topics (averaging 6.9 ESI topics), and six respondents who indicated none. Results are summarized in Table 2. A follow-up question asked individuals to identify all of the types of courses where ESI topics were included; the survey presented nine options (including "other" with write-in space). On average, the 97 chemical engineering faculty indicated 2.3 course types they taught that included ESI. Thus a one-to-one correlation between ESI topics and particular courses is only possible for the 28 chemical engineering faculty who only taught ESI in a single course type. Table 2 shows both the percentage of faculty who taught particular ESI topics in sophomore/junior engineering/engineering sciences courses (EES) among multiple course types (n=53) and only EES courses (n=10), with a similar approach for capstone design.

Table 2. Percentage of ESI Topics Taught in Courses by Chemical Engineering

ESI Topic	All *n=97*	FY Intro *n=32^*	FY Design n=13	So/Jr Eng Sci n=53^,10		Capstone Design n=43^, 6		Graduate level n=22^
Safety	79	84	**100**	75	60	88	100	77
Professional practice issues	66	72	**77**	74	70	70	67	64
Engineering decisions under uncertainty	66	75	**85**	75	70	72	50	73
Environmental protection	59	68	**77**	66	60	70	50	50
Sustainability / sustainable development	58	**69**	62	68	**70**	51	17	59
Societal impacts of technology	57	72	**85**	62	50	67	33	50
Ethical failures and disasters	57	69	69	64	40	**70**	33	50
Engineering code of ethics	48	63	54	49	30	**65**	33	45
Risk and liability	40	**56**	46	36	20	49	17	**50**
Ethics in design	39	56	62	34	10	**63**	0	36
Responsible conduct of research	36	47	54	34	30	33	0	**59**
Average # ESI topics	*6.9*	*8.6*	*9.3*	*7.2*	*5.2*	*8.0*	*4.2*	*7.7*

^Course among multiple types including ESI taught by the individual

- Other ESI topics taught in their courses by 21-12% of chemical engineering faculty were: ethical theories, social justice, engineering and poverty, bioethics; ESI topics taught by 7% or fewer of chemical engineering faculty were: nanotechnology (7%), privacy and civil liberties (7%), war/peace/military applications (5%), other (4%)

The survey then asked individuals to consider the one course they taught where they believed they most effectively educated students about ESI. Instructors were asked to write-in the course title, then characterized the course type (from among the 9 course-type categories), then indicated the methods that they used to teach ESI (from among 16 options including "other"), and the methods they used to assess the outcomes of ESI learning (from among 9 options including "other"; "do not assess" was an additional choice). Individuals were then given the opportunity to describe a second course that they taught which included ESI, and were asked to provide the same information for this second courses. The ESI teaching and assessment methods described by chemical engineering instructors are summarized in Table 3. The sections below describe the results for the most common course types reported by the chemical engineering instructors, with greater detail provided from the interviews, when available.

RQ3a: First-Year Courses

Among the 97 chemical engineering faculty who indicated the types of courses where they taught ESI, 33% indicated first-year introductory courses and 13% first-year design focused courses. It is uncertain to what extent some chemical engineering faculty may teach these courses but not include ESI. These individuals also taught ESI topics for chemical engineering students in other course types; on average, 3.3 and 4.1 different types of courses, respectively. For some chemical engineering faculty this may represent all of the courses they teach. Among those teaching FY introductory courses (and other course types), the most common ESI topics taught were safety, engineering decisions under uncertainty, professional practice issues, and societal impacts of technology. These were similar among the FY design instructors: safety, engineering decisions under uncertainty, and societal impacts of technology.

Nine respondents selected their first-year introductory course as the one course where they believed they most effectively taught ESI, and one additional FY introductory course was described. The most common ESI teaching methods described on the survey for these courses (Table 3) were: examples of professional scenarios (90%), in-class discussions (70%), and lectures (60%). On average, 5.5 different teaching methods were used in FY courses. The use of a combination of methods to teach ESI is likely a best practice, congruent with Vanasupa's [10] model. Discussions map to the social domain versus lectures to the cognitive domain. Professional scenarios illustrate how the material might be relevant in students' future careers. The most common methods used to assess the outcomes of ESI instruction were individual homework graded with a rubric (40%), individual reflective essays (40%), and surveys (30%); one (10%) did not assess the learning outcomes of ESI instruction.

Table 3. ESI Teaching and Assessment Methods used in Percentage of Various Course Types by Chemical Engineering Instructors

ESI Teaching and Assessment Methods	All (n=107)	FY Intro (n=10)	Soph/Jr Engrg (n=31)	Eng design (n=14)	Senior Design (n=27)	Graduate level (n=13)
Case studies	66	40	68	**79**	**78**	69
Lectures	64	60	52	71	70	77
Examples of professional scenarios	61	**90**	52	71	70	46
In-class discussions	59	**70**	61	43	56	62
Engineering design	46	10	29	**57**	**78**	23
Project-based learning	38	40	23	**43**	**52**	23
Videos, movie clips	31	40	32	29	41	23
Guest lectures	25	40	13	14	26	38
Reflection	24	30	23	29	15	38
Problem solving heuristics	22	20	16	43	26	8
Individual homework graded with a rubric	44	40	35	29	48	**62**
Group-based written assignment	39	20	29	**50**	**52**	23
Individual reflective essays	38	40	35	21	41	**46**
Test and/or quiz questions	35	30	26	**43**	**41**	23
Individual homework with right/wrong answers	23	20	19	29	30	15
Team ratings	19	30	10	7	33	23
DO NOT ASSESS ESI learning outcomes	9	10	**13**	7	4	8

- Includes 12 additional courses that include ESI described by 12 chemical engineering instructors
- fewer courses included: in-class debates (17%), think=pair-share (16%), other (9%), service-learning (7%), moral exemplars (5%), humanist readings (2%)
- Fewer courses included: surveys (8%), other (7%), individual standardized assessment method (DIT etc, 0%)

One interviewee described the pedagogical approaches related to ESI in an Introduction to Chemical Engineering course. At the beginning of the semester, students work in small groups to build a history of chemical engineering starting in 1908, when the American Institute of Chemical Engineers was established. The groups read about their time periods to identify five to ten events or milestones, positive or negative, related to chemical engineering. The students present their findings and the class develops a timeline of the discipline. The students then vote on which events they consider most significant, such as Chernobyl and the creation of the nuclear bomb, and the discussion during the second half of the class period focuses on those events. By researching the development of chemical engineering and discussing various contributions and disasters, the class gains an awareness of engineering ethics and socio-technical interplay throughout the last century. The instructor described the activity as an opportunity to incorporate "safety and ethics and sustainability talk all in one class period." The second ESI-related activity is a tour of a chemical manufacturing plant. Each group is tasked with asking an operator or engineer a question about professionalism and lifelong learning or safety and operations. The assignment encourages students to think about these professional and ethical responsibilities and increases their engagement in the tour. The third ESI course component is an ethics-related question on the take-home final exam that provides a workplace scenario and asks students how they would respond and what consequences they would consider. The test includes a range of questions and students are allowed to choose which they want to answer. The three components offer different avenues to introduce students to the importance of ESI at the beginning of their academic experience.

RQ3b: Engineering Science / Engineering Courses

Among the 97 chemical engineering faculty who indicated the types of courses where they taught ESI, 55% indicated sophomore/junior level engineering and engineering science courses. It is unclear what percentage of chemical engineering faculty teach these course types without including any ESI. Among individuals who taught sophomore/junior engineering courses for chemical engineering students, they included ESI topics in an average of 2.4 different course types. The most common ESI topics taught by these individuals were (Table 2): engineering decisions under uncertainty, professional practice issues, sustainability, and safety.

Sophomore/junior engineering/engineering science was the most common course type where chemical engineering instructors believed they most effectively taught students about ESI; 29 faculty described these courses; two additional faculty provided information on this type of course as a second setting for ESI instruction. These course titles included: chemical engineering principles, material and energy balances, thermodynamics, transport phenomena, mass transfer unit operations, and statistics. The most common methods to teach ESI in these core engineering courses (Table 3) were: case studies (68%), in-class discussions (61%), lectures (52%), and examples of professional scenarios (52%). The most common methods used to assess the outcomes of ESI instruction in these courses were: individual homework graded with a rubric (35%) and individual reflective essays (35%); 13% did not assess the outcomes of ESI instruction in their core engineering course. These instances without assessment align with notions of micro-insertion since the content is briefly introduced but not formally integrated into assignments that are evaluated.

One interviewee described a Heat and Mass Transfer course, where students learn about safety standards, ethics, and broader impacts through a case study provided by the Chemical Safety Board. The website includes a synopsis of an event in which a heat exchanger was designed using a flawed handbook. The students watch the summary video on their own time and come prepared to discuss it in class. The class splits into four teams with different foci: technical design options, human aspects, safety standards, and the company history that led up to the disaster. The teams research their respective topics and then report back to the class. The discussion explores the multi-faceted nature of the design failure with students "thinking beyond the numbers" to the social and ethical implications. In years when time is more constrained, the assignment is completed as homework with students answering questions about safety, broader impacts of design, and ethics in a company culture. The instructor described the activity as readily transferrable and implementable since the Chemical Safety Board is a "wealth of information" with cases "related to any core engineering problem you want." Discussions of ethics and broader impacts are also integrated into the class project on equipment sizing. The project is used as an opportunity to explore the implications of design choices with "practicality added into all the theory" in the course.

RQ3b: Design-Focused Engineering Courses (Non-Capstone)
Among the 97 chemical engineering faculty who indicated the types of courses where they taught ESI, 29% included ESI in design-focused engineering courses in the sophomore to senior year, not including capstone design (e.g. separations, reactor design). It is unclear what percentage of chemical engineering faculty teach these course types without including any ESI. The ESI topics taught by individuals teaching these course types were generally similar to average (e.g. 82% safety, 71% professional practice issues), with greater inclusion of ethics in design (54%). Fourteen individuals described these courses as settings for ESI education, with the most common ESI teaching methods in these courses of case studies, lectures, examples of professional scenarios, and engineering design (Table 3). The ESI learning outcomes were commonly assessed in these courses using group-based written assignments and test/quiz questions (Table 3). In many cases, it appeared that ESI might have been embedded within the design projects for the course; for example, one write-in response stated "Design project must discuss safety issues."

RQ3c: Senior Capstone Design
Among the 97 chemical engineering faculty who indicated the types of courses where they taught ESI, 44% included senior capstone design. These individuals indicated that they taught ESI in an average of 2.8 different course types, and an average of 8.0 different ESI topics. Common ESI topics included (Table 2) safety and professional practice issues. Senior capstone design was described as their most effective course for ESI instruction by 22 chemical engineering faculty. In capstone design the most common ESI teaching methods (Table 3) were: engineering design (77%), case studies (73%), examples of professional scenarios (73%), lectures (68%), in-class discussions (59%), and videos (45%). The most common ESI assessment methods (Table 3) were: group-based written assignment (50%), individual homework graded with a rubric (50%), individual reflections (41%), and test/quiz questions (32%); only one (5%) of the senior capstone design instructors indicated that they do not assess the outcomes of ESI instruction in their course.

In a two-semester senior capstone design course taught by an interviewee, teams of 4-5 students design improvements to an on-campus pilot-scale papermaking facility. The course incorporates video case studies of ethical situations in the workplace and the associated guiding questions to build a foundation of ethical awareness. The writing assignments, in-class discussions, and engineering calculations that correspond with the videos cover professional and environmental ethics and safety. These case studies offer the opportunity to generate conversation and reflection while getting students to understand social, environmental, and ethical implications of technical engineering scenarios. Exposure to engineering ethics through these case studies also help prepare the students to consider ethical dimensions in their own projects. The justification for the project alternatives requires considerations such as safety and environmental impact. These issues are embedded in the decision-making process and project rubric to reinforce their importance.

RQ3d: Elective Courses

An upper-division elective course on sustainable energy was described in detail in one of the interviews. The course facilitates ethical development by focusing on the economic, political, social, and environmental aspects of energy use and extraction to illustrate the importance of looking beyond technical factors in engineering decision-making. By considering all of these aspects within the context of a technical elective, the students understand that ethical issues and broader impacts are organically integrated with engineering decisions and cannot be partitioned. In a class activity, the students are split into five groups representing the economic, political, environmental, social, and technical aspects of hydraulic fracturing. Students do research and watch informational videos, in addition to solving technical problems. The intervention was designed to "cover both the fundamentals that need to be covered as well as their broader impacts." The class then engages in a discussion guided by open-ended questions to learn about the different perspectives and interests in the nationally contentious and locally relevant issue. Students are asked about their opinions on hydraulic fracturing before and after the intervention to track how their perceptions change. In a second activity, students work in groups to create informational videos regarding the sustainability considerations involved in their chosen energy topic, such as solar, wind, or fossil fuel. The project engages "students to explore the broader impacts of engineering content, trying to related them to the social impacts, environmental impacts, economic impacts, political implications" to give them a "holistic" view of energy. The videos also serve as a valuable resources and opportunity for discussion.

RQ3e: Graduate Level Courses

Among the 97 chemical engineering faculty who indicated the types of courses where they taught ESI, only 23% stated that this included graduate-level courses. However, among those who did teach ESI in graduate level courses, ESI was integrated into an average of 3.1 different course types (perhaps all of the courses they teach), and an average of 7.7 different ESI topics were taught. The most common ESI topics included (Table 2) safety, engineering decisions under uncertainty, responsible conduct of research, and risk and liability.

Graduate-level courses were described as the most effective setting for ESI education by 12 chemical engineering faculty (55% of those who indicated teaching ESI in graduate-level courses; 7 also cross-listed as senior-undergraduate electives); one additional graduate course was described as a second course for ESI instruction. Examples of these courses are: introduction to research, nanoscale transport, applied cellular and molecular biology, and green engineering. The ESI teaching and assessment methods used in the graduate-level courses were generally similar to those found in the undergraduate courses (Table 3), with the exception of significant use of in-class debates in the graduate courses (31%).

RQ4: Co-curricular activities that include ESI

When asked where they believed undergraduate students in their program learned about ESI, a fairly large percentage of chemical engineering instructors indicated a co-curricular engineering professional society (35%) and/or co-curricular engineering service group (such as Engineers Without Borders, Engineering World Health; 29%); among the write-in responses associated with other settings, co-ops, internships, etc. were listed. These co-curricular experiences may provide ESI education for some students. Because participation is voluntary, which supports the motivation construct of autonomy [10], students' receptiveness to learning about ESI may be higher in co-curricular settings than in courses. However, voluntary student participation also means that programs can't rely on all students learning necessary ESI information solely via co-curricular settings.

A large number of the survey respondents indicated that they believed students learned about ESI in co-curricular activities that they personally mentored, including 90% of the 90 co-curricular survey respondents (8 mentored a co-curricular activity and indicated that no ESI topics were included, 1 indicated that they did not mentor any co-curricular activities) and 53% of 17 curricular survey respondents (another 6% indicated they mentored co-curricular groups but did not believe that students learn about ESI there; 41% stated they mentored no co-curricular activities). Across all types of co-curricular activities (professional societies, research experiences, honor societies, design competitions, engineering service groups, and other) the activities that chemical engineering faculty mentors believed contributed to students' education on ESI (among four options presented on the survey) were: lectures, presentations, and/or guest speakers (84%), discussions (76%), working with a community (48%), and design projects (43%). Write-in comments elaborated on these general responses, such as: "Students do outreach and tutoring in the community, confronting directly the consequences of poverty. They also learn about topics from guest speakers." Only 16% of co-curricular activities reported assessing the outcomes of ESI education; these were generally REU sites. The specific ESI topics taught in co-curricular settings were only identified on the co-curricular survey (results in Table 4); 32 respondents described two distinct co-curricular settings.

Table 4. Co-curricular activities mentored by chemical engineering instructors: percentage including particular ESI topics

ESI Topics	All types (n=121)	AIChE (n=38)	Research (n=26)	Honor society (n=20)	Design Gp (n=10)
Professional practice issues	66	79	62	55	50
Safety	63	71	85	25	70
Societal impacts of technology	50	45	31	50	40
Sustainability	50	42	58	25	60
Engrg decisions under uncertainty	38	26	42	10	90
Responsible conduct of research	38	21	81	20	60
Environmental protection issues	36	37	38	5	40
Engineering code of ethics	31	45	23	35	20
Ethical failures and disasters	19	29	19	5	10
Risk and liability	29	34	19	5	70
Ethics in design	16	18	15	0	30
Engineering and poverty	13	8	4	5	20
Social justice	13	11	8	5	30
No ESI topics	7	5	0	25	0

Less than 10% of all co-curricular activities mentored by chemical engineering faculty included: bioethics (7%), nanotechnology ethics (6%), other topics (5%), privacy and civil liberties (4%), war, peace, and military application (3%), and ethical theories (2%).

There were 38 respondents who mentored student chapters of the AIChE at their institution. Among this group, ESI topics included by more than half were: professional practice issues (79%) and safety (71%). The majority of AIChE mentors reported that the students learned about ESI topics via lectures, presentations, and/or guest speakers (68%). These guest speakers included individuals from industry, academia, and alumni, and write-in comments noted that these presentations sparked discussion of ESI topics. Some of the AIChE chapters (34%) also described outreach and volunteer work in the community, such as "working with headstart on science education" and "outreach activities with K-8 students, judging science fairs." More details on outreach-related AIChE activities have been published [27]. Tours of industrial facilities were also mentioned, with these activities providing students with a first-hand experience of safety-related issues. None of the AIChE mentors indicated that ESI learning outcomes were assessed. Additional professional societies mentored by chemical engineering faculty included: SWE (n=3), SHPE (n=3), BMES (n=2), NSBE (n=1). These results are included among the overall co-curricular data, but not presented in detail given low response numbers.

There were 26 of the chemical engineering instructors who indicated that students they mentored in research learned about ESI via this co-curricular activity; 13 were explicitly invited to take the survey due to serving as PI or coPI of an NSF-funded REU site. The ESI topics most commonly associated with research activities were: safety (82%), responsible conduct of research (79%), sustainability (57%), professional practice issues (57%), engineering decisions under uncertainty (43%), and environmental protection issues (39%). In the context of research, discussions were the most common method that faculty mentors believed students learned about ESI (82%). More explicit examples described by research mentors were: seminars focused on ESI topics, with discussion; "we use case studies and work in groups to discuss plagiarism, lab notebook taking, ownership of lab notebooks, proposal writing, etc."; and "The long-term goals of the research are discussed with the mentor and with other students. The student presents his/her research to peers and thinks about the implications of their work." In contrast to professional societies, among the research mentors 43% indicated that they assessed student learning of ESI. Assessment methods described by the research mentors included: CITI online training modules that were scored, weekly journals, surveys, informally via student presentations, and other "assessments" by external evaluators. Previous publications have described ethics-related learning outcomes from REU site activities [28-29], but not specific to chemical engineering.

There were 20 chemical faculty who mentored engineering honor societies (half Omega Chi Epsilon, half Tau Beta Pi). Among different types of co-curricular activities, these groups had the highest percentage of mentors that reported no inclusion of ESI topics. Among the 15 honor societies that included ESI topics, 80% included ESI via lectures, presentations, and/or guest speakers; 73% reported working with communities, and 53% included discussions of ESI topics. Write-in comments described how engineering students learn about broader impacts and/or ethics in this informal setting. One example describing guest speakers was: "Students invite professional, practicing engineers to speak on this topic directly, or indirectly about safety, environment, research practice." An example of working with communities was, "Students from the club learn about the broader impacts of issues related to engineering while preparing to volunteer at local community events (e.g., outreach activities with K-8 students, judging science fairs). This aspect (i.e., broader impacts) of engineering is often the first thing that engages members from the community." None of the mentors of honor societies reported assessing the outcomes of ESI learning.

Only 10 chemical engineering faculty described co-curricular design competitions that they mentored, including the ChemE car (n=6) and the US EPA P3 competition (n=3). Here students learned about a fairly wide range of ESI topics directly through their design projects (90%). A write-in comment that described how the students learn about ESI through the ChemE car competitions was: "I ask the student teams to talk about the broader impacts and applications of the technologies they utilize in their car designs when they present their cars to other groups and the public." Another example is: "Students must build a car that works. They must extensively document safety and mitigate risk. They do some outreach with the car at local schools. Also a theme of the competition includes sustainability." In contrast, examples of the P3 write-in responses are: "By interacting with the communities for which the project is intended" and "travel to off-grid villages in Africa to see very different way of living." Only two mentors reported assessing the outcomes of students' ESI learning; in the open-ended response to describe how, one wrote: "in discussions and in feedback on their presentation, which is required for the design competition."

Summary and Conclusions

This paper explored the perceptions and practices of chemical engineering faculty on students' education about ESI, via both courses and co-curricular activities. Although most felt that the ESI education of both undergraduate and graduate students was insufficient, the vast majority of the survey respondents taught ESI in their own courses. Perhaps some of these individuals believe that they are not teaching ESI effectively, reaching the breadth and depth of learning outcomes they believe to be important; developing students' ethical reasoning abilities is difficult and many engineering faculty have not received explicit training in ethics education themselves. Alternatively, individuals may be invested in ethics education, but believe that they cannot achieve important curriculum-level learning objectives for ethics and societal impact issues on their own, and greater commitment is needed within their department as a whole. Given the widespread differences that were found in the types of courses that chemical engineering faculty identified as contributing to the ESI education of students in their program, it appears that the majority of programs may lack a coordinated approach to ESI education. Other than a programmatic commitment to the inclusion of ESI in capstone design (or not) or an entire required course on ethics (or not), faculty may integrate ESI on a largely ad hoc basis when they personally believe that it is important. The revised ABET criterion 3 outcome (4), targeting an ability to recognize ethical situations and make informed judgements about them, may provide an impetus for chemical engineering faculty to come together to critically examine the ESI education in their undergraduate program, as well as extending this exploration to the graduate level. This coordinated approach should yield a more well-rounded ESI education for students across a breadth of important topics.

The paper provides numerous examples of ESI-related topics, teaching methods, and assessment methods that can be used in any chemical engineering education setting. Faculty need not invent novel ESI teaching approaches, but can draw on prior experiences of others. Faculty are encouraged to consider including ESI, if only briefly, in all of their courses. This micro-insertion approach will not detract from other learning objectives in the course. There are published examples of integrating ESI into first-year courses [21], professional development courses [17, 20], electives [19], and capstone design [23]. Repeated integration of ESI into core chemical engineering courses [e.g. 14-16, 18, 22] will help students to recognize that issues of ethics, safety, environmental impacts, and sustainability are present in all engineering contexts, even those that may at first seem purely technical. Exposure to ESI issues across a range of settings will help students to develop improved abilities to recognize these elements in their work and make informed decisions about them. Enhanced ethics knowledge and reasoning should then result in ethical behavior in their work as chemical engineers.

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