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Faculty Perceptions of the Most Effective Settings and Approaches for Educating Engineering and Computing Students About Ethics and Societal Impacts

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Abstract
Teaching students about ethical responsibilities and the societal impacts of engineering (ESI) is an important part of undergraduate education. Despite the inclusion of these topics in accreditation criteria, professional codes of ethics, and engineering bodies of knowledge, there is little consensus on the most effective approach to educating students about ESI. Between September 2016 and April 2017, 37 interviews with faculty experienced in ESI education were completed. The interviews were designed to gain insight into the courses or co-curricular activities in which the educators teach ESI. The semi-structured interviews explored the teaching approaches used, including topic selection, pedagogy, and assessment, as well as motivating factors in the course design, perceptions of student impacts, and the overall institutional culture at the school in regards to ESI education. The conversations illuminated a range of perspectives regarding the most effective ways to educate engineering and computing students about ESI. Emergent, thematic coding of the interview data revealed diverging opinions on whether the topics should be taught in curricular or co-curricular settings, in required or elective courses, by engineering or non-engineering faculty, and in standalone ethics courses, integrated into technical courses, or across the curriculum. The results highlight different approaches suggesting best practices could be better clarified based on context and setting. Despite the varying opinions on settings and approaches, all of the interviewees expressed the importance of integrating ESI into engineering education to foster a sense of ethical awareness and responsibility in students.

Introduction
The new ABET student outcomes put additional impetus on teaching ethics by requiring that students attain “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” (outcome 4) [1]. The outcome mandates a higher level of learning than “an understanding of professional and ethical responsibility” (outcome f) [2]. The new criteria demand that programs demonstrate that their students are able to recognize their responsibilities and make sound choices, higher levels of cognition and moral development. This change, plus the ever evolving demands of engineering in an increasingly globalized and technology dependent world, put additional responsibility on engineering programs to effectively teach students about ethics and societal impacts (ESI). ESI includes microethics, the decisions and responsibilities of individual engineers, and macroethics, the profession’s collective responsibility in terns of societal implications of engineering and technology [3, 4].

Despite the growing recognition of the importance of ESI education, there is little consensus on the most effective approach. A variety of curricular models have been advocated in the literature. Ethics across the curriculum (EAC) is a holistic and intentional model of integrating ethics into courses throughout the engineering program. This approach has been widely recognized as an aspirational curricular integration strategy [5-7]. EAC entails directly incorporating ESI into a variety of courses throughout students’ education including discussing ESI in the context of relevant content in core engineering courses. ESI can also be taught in a dedicated course [8, 9].

This standalone course can be offered through engineering or through a different department such as philosophy, liberal arts, or theology. One of the most effective examples of this approach may be the 3-credit course at Texas A&M that is required for all students and co-taught by faculty members from engineering and philosophy [10]. Another approach is to teach ESI via self-contained modules in existing courses. This approach can be delivered through an ethics lecture by the instructor or guest speaker often in an introductory engineering or capstone design course. For example, in a survey of 1216 respondents who reported teaching ESI in their courses, 40% incorporated these topics into capstone design [11] and 34% in introductory courses [12]. Team-teaching, collaboration between engineering faculty and an ethics specialist, is another way to blend the technical and theoretical facets of ESI.

Outside of the classroom, co-curricular activities, such as design competitions, service organizations, or student chapters of professional societies, can afford the opportunities to teach engineering and computing students about ESI [13]. In these contexts, for example, ESI can be discussed by guest speakers, integrated into community-based projects, or taught through professional codes [14, 15].

Programs can also implement a hybrid model of the aforementioned approaches, such as offering an ethics-focused course and integrating ethics across the curriculum. Strengths and limitations of the different approaches are summarized in Table 1.

Table 1: Approaches to teaching ESI

Curricular Model	Strengths	Limitations
Ethics across curriculum	-Can be integrated into any place in the curriculum -Sustained, repeated exposure increases ethical awareness and recognition [16] -Demonstrates the relevance of ethics to engineering [3] -Contextualizes ESI [7] -Engages and empowers engineering faculty to be involved in teaching ESI [17] -Supported by moral development theory and studies [17]	-Engineering faculty need to be willing and able to teach ESI -Need widespread faculty support to integrate cohesively -Limited time to discuss background of relevant issues [16] -Lack depth and continuity [3] -Challenging to implement [7]
Stand-alone ethics course	-Can cover a wider depth and breadth of topics -Attracts qualified teachers [16]	-Increased staff demand [3] -Difficult to find space in already packed curriculum [17] -Gives perception that ESI is not relevant to or required in engineering [16]
Modules	-Deeper coverage of ethics than brief reference in the context of core engineering courses [5]	-Can appear discontinuous

Curricular Model	Strengths	Limitations
Team teaching	-Diverse expertise from engineering and humanities perspectives [7]	-Depends on willingness of engineering faculty to collaborate and teach these issues [7]
Co-curricular activities	-Teach ethics in the context of engaging projects and opportunities [6]	-Treats ethics as voluntary [18]

The Four-Domain Development Diagram (4DDD) is a theoretical framework for engineering education that incorporates moral and ethical development along with other constructs [19]. The 4DDD illustrates how the social, affective, psychomotor, and cognitive domains influence learning. The causal loops within the model illustrate the interconnectedness of constructs that shape moral and ethical development. 'Engagement active learning' ('active involvement in the learning process') enforces 'mastery' (competence), which builds 'systems thinking' ('the ability to see the whole and establish a framework for seeing inter-relationships', which increases an 'understanding of the broader context' ('a knowledge of the connections between the subject that is being studied and its larger implications for one's self and society') [19, p. 72]. Motivation, at the core of the model, is driven by 'interest, value, and autonomy' [19, p. 70] and guides students in the learning process. The model aligns with importance of bridging micro and macroethics by illustrating the connection between the broader context and ethical development. By mapping the constructs, the model provides a 'potential strategic path to increase moral and ethical development' [19, p. 73] to guide the design of learning environments to best motivate engineering students. The model supports the inclusion of ESI in multiple instructional settings and with a variety of methods to effectively facilitate ethical development by tapping into the different domains and the reinforcing loops that link them.

There is a range of curricular models for ESI education, each with advantages and disadvantages. Consensus is difficult to reach because the circumstances that enable or impinge certain approaches are often unique to each program and institution. This study examines the perspectives of educators who teach engineering and computing about ESI to understand their perceptions of different approaches to see if the opinions converge on an optimal solution.

Research Question

What educational settings and curricular approaches do faculty members perceive as effective opportunities to teach engineering and computing students about ethics and societal impacts? What are the merits and limitations of these integration strategies?

Methods

Data Collection

The research presented in this paper is situated within a larger, multi-year study on macroethics education. The broader study began with two online surveys in spring 2016 to understand the national (and to a limited extent, international) landscape of ESI education. The curricular survey asked respondents to select the ESI topics they teach in their courses (18 options, other, and none), the types of courses (9 options, other, and none), the teaching methods they use (15 options, other, and none), and the assessment strategies (8 options, other, and none). After answering the questions on their courses, respondents were asked how they teach ESI in any co-curricular activities they mentor or advise. The co-curricular survey included the same questions but started with co-curricular then moved to questions on courses. The surveys concluded with identical questions regarding perceptions of where undergraduate engineering students in their programs learn about societal impacts of technology and whether undergraduate and graduate students receive sufficient education regarding ethics and societal impacts. The surveys included an open-ended question to share thoughts about ESI education and an invitation for respondents to provide their email address if they were interested in being contacted for a follow-up interview to share their experience teaching students about broader impacts and/or ethics. The data collected during the interviews are the focus of this paper.

Of the 1448 survey respondents, 230 expressed interest in participating in an interview. The interviews were designed to learn more about the courses and co-curricular activities that the educators described in the surveys and to understand their broader experience teaching engineering and computing students about ESI. The first step in this phase of the study was deciding which survey respondents to contact with the goal of completing 36 interviews. Selection was based on an iterative and collaborative process within the five-person research team. Broadly, we hoped to interview educators who represented a range of disciplines, topics, course types, and institutional settings and who were involved with high impact ethics instruction. For more detailed information on the selection criteria of each team member, see [20]. After individually reviewing the survey responses of the 230 educators, each member of the team proposed five people to contact for interviews. This process generated a list of 19 names since there was some overlap in recommendations. These educators were contacted via email in a first wave of invitations. All but one responded to the invitation and 16 interviews were completed. The process was repeated to generate a second wave of invitations with 15 educators recommended and contacted. Through this iteration, 10 interviews were completed. This process was repeated for a third and final time with the research team creating a list of 18 names and 11 interviews were conducted. In the second and third waves, selection became more intentional to include a range of settings and disciplines. For example, in the first wave, mechanical, civil, and environmental engineering were well represented so the next set of invitations included more educators from biomedical, chemical, and nuclear engineering. There was also a dearth of co-curricular activities in the first wave so an effort was made to include those settings in later waves of invitations. In total, 52 invitations were sent and 37 interviews were completed between September 2016 and April 2017.

The first author conducted all of the semi-structured interviews over Skype or phone. Consent forms were emailed to the participants prior to the interview and verbal consent was collected at the beginning of the interview. The interviews lasted 30-70 minutes and were audio recoded using Callnote. All of the interviews were guided by the same script. An additional question was asked of educators with industry experience to understand how that work impacted their teaching. Interviewees who were educated outside of the United States or who currently teach abroad were also asked about international perspectives. After each interview, a two-page summary was written by the interviewer and emailed to the interviewee for a member check [21]. After the member check, a pseudonym was assigned to the participant using a random name generator [22].

Participants

The 37 interviewees all taught ESI to engineering and/or computing students; 34 are included in the present study due to recording errors with two interviews that prevented transcription and one interviewee that did not explicitly discuss perceptions of effective settings. Interviewee demographics are summarized in Table 2. The educational backgrounds of the 34 individuals varied: 22 with engineering degrees in civil, industrial, electrical, mechanical, environmental, computer, chemical, and biomedical; seven with non-engineering degrees including anthropology, ethics, linguistics, philosophy, psychology, sociology, and education; and five with both engineering and non-engineering degrees of education, public policy, business, and journalism. Demographic information on the complete set of 37 interviewees is available [20].

Table 2: Demographic characteristics of interviewed faculty

Demographics	Sub-set included in analysis (n=34)
Gender	
Male	22
Female	12
Academic Rank	
Full professor	14
Associate professor	6
Assistant professor	10
Senior instructor or other full-time non-tenure track	2
Departmental/college staff member	2
Degree	
Engineering	22
Non-engineering	7
Both	5
Department appointment	
Engineering	27
Non-engineering	4
Both	3
Institution type	
Public, Bachelor's	1
Public, Master's	4
Public, Doctoral	17
Private secular, Bachelor's	2
Private secular, Master's	2
Private religious, Bachelor's	2
Private religious, Master's	3
Private religious, Doctoral	1
International	2

Data Analysis

Using the audio recordings, content logs were developed for each of the interviews [23]. The content logs included the interviewer questions and a summary of the respondent's answer with time stamps. After all of the content logs were written, sections of the interviews related to the perceptions of the most effective settings and approaches for ESI instruction were transcribed.

These segments could be in direct response to a question or could arise spontaneously in the discussion. Interviewees were asked to describe the course or activity in which they teach ESI, the pedagogical approach they use, and what makes that approach effective. The script also included questions related to motivations in designing the ESI instruction, challenges encountered while teaching ESI, and student interest in the material. In total, there were 82 segments across 34 interviews that were relevant to the topic of this paper. The interview segments were analyzed using emergent, thematic coding [24]. The first author coded all of the segments in Excel and the third author coded a random sub-set of 40 segments for inter-rater reliability. Agreement was tested in SPSS 24 using Cohen's kappa with almost perfect agreement inferred at values between 0.81 and 1.0, substantial agreement between 0.61 and 0.80, and moderate agreement between 0.41 and 0.60 [25]. For the four codes that did not initially reach at least moderate agreement, the two coders discussed all of the segments for which they disagreed until they converged on the appropriate description. Only the codes with a frequency of at least four are discussed.

Results and Discussion

The codes related to perceptions of effective educational settings fell into three broad categories: curricular approach, instruction, and course characteristic.

Curricular Approach

Interviewees discussed a range of curricular models for ESI education. The related sub-codes, definitions, frequencies (counts per 82 segments and percentages of interviewees), and kappa values are displayed in Table 3.

Table 3: Curricular approach sub-codes

Sub-code	Definition	Frequency (n of 82 segments)	Frequency (% of 34 individuals)	Kappa
Ethics across the curriculum	Integrating ethics across the curriculum is noted as an effective strategy for teaching ethics	25	50	0.84
Humanities and social sciences	Merits or limitations of offering ESI through the humanities/social sciences/philosophy department or from the philosophical perspective are discussed	14	26	0.68
In context	Approach of teaching ESI in the context of design projects or technical content is mentioned	24	53	0.50
Module	Teaching ESI through self-contained modules in existing courses is discussed	5	12	0.84
Co-curricular	Advantages or disadvantages of teaching ESI in a co-curricular organization or activity are noted	11	21	0.88

Ethics across curriculum

Ethics across the curriculum was discussed by 17 of the 34 participants (50%). This curricular approach was promoted as a way to contribute to students' understanding of ESI while also conveying that ethical and social responsibility, like any engineering skill, is reinforced throughout the curriculum. One interviewee who teaches ethics in statics and dynamic systems at a private master's medium program [26] commented,

> I think the big problem, and it's not just with ethics, it's with a lot of things, it's that students have a hard time making connections from one thing to another. They don't transfer things well…you have to do it multiple places so that they disconnect it from the location.

Integrating ethics across the curriculum mitigates the risk of ESI being relegated to the non-technical skills that students do and dismiss. One interviewee who incorporates ethics case studies and discussions into capstone design at a private master's small program [26] noted,

> it seems like it's a more effective educational process if you have it show up frequently and in various contexts rather than having a course that you take on safety and ethics and then that's that. It's another hoop that the students jump through and they don't have to worry about it ever again… it seems to me that it's better if it's not taught in a way that pigeon holes it as this isolated requirement in one course that they don't have to think about ever again.

EAC can help shift the paradigm of treating ethics as a requirement to 'fulfill and forget' to understanding its intrinsic value in engineering. One interviewee teaches at a public doctoral university with higher research activity [26] that is introducing macroethics across the curriculum; this individual described the intentional EAC design process and contrasted it with the current state of engineering education.

> So what we wanted to do was create multiple spaces across the curriculum that are engaging both the technical and the social simultaneously… and when we looked at the curriculum, we looked at three major portions of the curriculum. The biggest portion in terms of course numbers is engineering science courses. And really ethics and broader social impacts are almost completely invisible in the biggest portion of an engineering curriculum. And then we looked at the social sciences and humanities… it's often divorced from the technical… then in design, I think that's a great area, but it's less than 15% of the courses that students take in an undergraduate career… then in the other 85% it's completely invisible, you're going to think, as an engineering student, just doesn't matter. This broader impacts, if it had really mattered, my professors would have mentioned it more. But we're trying to change that culture.

Teaching ESI throughout the educational experience conveys the inherent interconnectedness of ethical decision-making and engineering. A psychology professor who teaches at a private religiously affiliated baccalaureate college with arts and science focus [26] developed an ethics course for computer science students that is integrated into the program. He described how the whole department bought in to the importance of ethics education to craft an EAC approach.

> It is integrated into the whole program. Students are introduced to the idea of socio-technical systems in the introductory course then they get the full-blown socio-technical systems ideas in the ethical issues in software design course and they learn about ethical

> reasoning and do this whole consulting project and then everyone participates in a senior project… with a required ethical analysis with that project… this makes it really clear that all of the computer science faculty take this course seriously and they see it as an important part of the major.

These comments support the integration of ethics throughout the undergraduate experience because this approach helps students bridge ESI content and technical material and demonstrates that ESI is inherent to engineering and not an isolated requirement.

<u>Humanities and social sciences</u>

Participants voiced a range of opinions of the merits and limitations of teaching ESI through a humanities/social sciences (HSS) department or perspective. Advocates of this approach argued that it broadens students understanding of ethics and offers a perspective that complements the technical focus of the curriculum. An interviewee who has a sociology background and teaches first-year courses to engineering students at a technical institute in the European Union noted,

> they [engineering students] have to be taught different things, they have to do sociology in a sense… they need to hear more about different approaches, they need to think about societal issues and take some stuff from STS, wider sociological frames.

An engineering professor who formerly taught ESI in standalone courses and thermodynamics at a private baccalaureate college with an arts and science focus [26] commented that the material is most effectively taught through a range of settings and perspectives, including HSS.

> There's a way of thinking that philosophers bring that an engineering faculty member is not going to teach to students and I really think students need that moment of thinking like a philosopher as part of their education… students are supposed to be exposed to different ways of thinking about the world, they ought to be having ethics presented in that way.

A philosophy professor who teaches at a public doctoral university with highest research activity developed a course focused on modern scientific and engineering ethical controversies. He noted that his education and training in ethics provide a level of expertise that engineering professors are not able to offer. When asked whether this background enabled him to better communication and facilitate ESI discussions in the classroom, he responded, "Yes. 100% and it's not even any amount of hubris… I've been doing ethics a very long time compared to my engineering colleagues." An interviewee with a PhD in ethics who teaches at a private master's larger program [26] shared a similar opinion.

> You want to have an entire course on it that's taught by someone who has a PhD in an ethics-related discipline so there are a couple of benefits to that, um first of all, you got a professor who has a much deeper knowledge of the material but also…the idea of having to bring in a specialist shows that doing ethics well isn't something you anybody can just do off the top of their head, it requires study, that it requires knowing a certain amount of specialization that isn't just a flippant thing you can just do and dismiss, it really requires somebody to have a deep knowledge of ethics, it's something you study hard for a long time and its something that has complexity to it and that not everybody can just teach it in their class.

Teaching by a specialist shows the rigor and nuance of ESI and that it should be taken seriously. However, other participants voiced diverging perspectives related to this sub-code. An interviewee who teaches a professionalism course in civil engineering at a private master's larger program [26] noted that the department was intentional in its decision to teach ethics in-house as opposed to offering it through the philosophy department on campus.

> A lot the faculty said, civil engineering, we deal with public health, public safety, there's no situational ethics for public safety, it's binary, the public is either being safe or the public isn't being safe and so you can't say 'well it depends on the context'… after looking at some material, they felt that some aspects of the philosophy department are about as far as you wanted to get from teaching students about ethical responsibility to the public.

The department held a perception that the philosophical perspective of teaching ethics was incompatible with the black and white nature of decision-making when it comes to safety. The interviewee who is part of the macroethics across the curriculum program expressed that teaching ethics through HSS was limited because it lacked the technical context that makes it relevant to engineering.

> The risk if you leave it to the quote on quote experts in philosophy or some other area is that they just get the philosophy slant, but - or if you just leave it to someone in humanities and social science department, you don't often get the deep rich connection to technical projects.

Teaching ESI through HSS offers the opportunity to broaden students' perspectives and provide a different lens through which they can negotiate ethical and social dilemmas. However, the approach might be more effective if it is supported by engineering faculty and connected with engineering content to demonstrate the relevance.

<u>In context</u>

Teaching ESI in the context of technical content and design projects was another curricular model mentioned by 18 of the interviewees. The design of this approach might be less cohesive and intentional throughout the engineering coursework than EAC but similarly integrates ESI into core engineering content. An interviewee at a public doctoral university with highest research activity [26] who incorporates ethics into a graduate-level biostatistics course through discussions of sample size and responsible conduct of research noted that such topics are inherent to statistics.

> Discussions of ethics are almost inevitable when you put things in the real context, things only become devoid of moral component when they're viewed in isolation. When you get something to where it's only this tiny narrow piece of the world that you're looking at a time that you're able to recognize it as something that does not have morality tied into it, and you have it in a broader context and you see how it's going to impact the world, then I think, like I said, it falls very naturally to it [statistics].

This approach not only affords the opportunity to tie together ethical and societal implications with technical content, it also makes the material more meaningful. When students learn that using statistics to design their research studies can impact the amount of taxpayer money and number of animal or human subjects they need, it becomes more relevant than just plugging calculations.

Design and service projects also offer the chance to teach ESI in context. Working on real projects with clients exposes the human side of engineering. An interviewee who teaches a range of industrial engineering courses at a public special focus engineering school noted that the department most effectively teaches ESI through project work.

> One of the best ways really is in the community projects we have them do. We do a lot of service learning projects… we definitely do that in the context of the community service learning projects and we do those projects in all of the courses that I teach so that's probably the best way… students got an appreciation outside of typical textbook things on those projects… we value as much the social interaction and the community impacts that it's going to have.

This approach enables students to learn about engineering design, community engagement, and technological impacts simultaneously while tapping into their interest in the project and responsibility to their client.

<u>Module</u>

Modules can be embedded in introductory, design, or core classes but are distinct from being in-context since they are self-contained and can include an ethics-focused lecture, guest speaker, or project. Although this approach is valuable for introducing ESI in limited curricular space and can be used to fulfill accreditation requirements, some interviewees voiced concerns over its limitations. An interviewee who teaches a one-credit ethics course at a private master's larger program [26] noted this was the bare minimum to discuss ethics since "you cannot possibly cover it with one or two lectures." Another interviewee who has developed and taught ethics courses and was responsible for most of the ethics instruction in the department at a public doctoral institution with highest research activity [26] commented on the disadvantage of modules in terms of student learning.

> I parachute in for the drive-by ethics session, I don't think it's that effective because I'll ask a student a year later, what do you remember we did that class session, 'well we talked about ethics and might have watched a video and talked about it.' If they do no homework and have no thinking about it, it's not reinforced then I think there is very little residue.

Modules are limited because ESI is too complex and important of a topic to cover in one or hour hours and this approach is not as conducive to impactful learning without reinforcement.

<u>Co-curricular</u>

The advantages and disadvantages of teaching ESI in co-curricular activities were also discussed. The aforementioned interviewee who teaches statics and dynamic systems also incorporates ESI into co-curricular activities including the Society of Women Engineers and Tau Beta Pi; this individual mentioned that exposure inside and outside the classroom is valuable.

> In a less formal setting, it's also something that I think faculty advisors, and faculty in general, should do through casual interactions with students and part of that is because you get things across in a different way.

Co-curricular activities provide different contexts and can use various pedagogical approaches that engage students differently than in the classroom. The interviewee who is part of the macroethics across the curriculum program discussed that leveraging out-of-classroom experiences with in-classroom discussions was effective.

> Yeah, a lot of the students are in our humanitarian engineering program and some of them are also in EWB. And we highly encourage them to bring those kind of real-world, applied experiences to their classrooms…those are highly relevant. And a lot of times the students will write on the projects that they did and what they wished they had known before they took the course.

Those lived experiences provide rich context for students to understand ethics and societal impacts of engineering design. However, some participants described the drawbacks of relying on co-curricular settings to teach ESI. One interviewee at a public doctoral university with higher research activity institution [26] noted the service organizations that send students to foreign countries for engineering projects and have minimal follow through after completion are not conducive to teaching ESI since the organizations are not built on foundations that emphasize the ethical and societal impacts of the work.

> And, you know, and contrast that to the situation where we can have a club that says 'we're going to go to Nicaragua and build bridges.' And we get there and we do all the work and we put in a bridge and say 'there is your bridge.' And, you know, so that has no community involvement. That has no sustainability component because somewhere down the road, someone's going to say 'huh the bridge broke when the foreigners going to come back and fix it?'

In his experience, the humanitarian engineering courses offered at the institution were more effective opportunities for learning about ESI than engineering service organizations because the courses were very deliberate about teaching community engagement and sustainability as opposed to focusing just on the product or project.

Instruction

In addition to the range of curricular approaches, interviewees offered insights on effective means of instruction. Sub-codes under this theme include engineering professors, educators with industry experience, and interdisciplinary collaboration, as shown in Table 4.

Table 4: Instruction sub-codes

Sub-code	Definition	Frequency (n of 82 segments)	Frequency (% of 34 individuals)	Kappa
Engineering professor	Advantages or disadvantages of having engineering faculty teach ESI in their courses are noted.	9	21	0.53
Industry experience	Role of engineering faculty's experience in industry is mentioned	9	21	0.88
Interdisciplinary collaboration	Collaboration between different disciplines in the development of ESI instruction is noted.	8	18	0.54

Engineering Professors

Although engineers might be reticent to discuss ESI in their courses, participants advocated that their understanding and representation of technical content affords an impactful opportunity to teach ESI. An interviewee at a public doctoral university with highest research activity [27] who teaches ethics and entrepreneurship courses to engineering and computing students commented on this approach. Although she has a non-engineering background, she commented that it is important for engineering faculty to include these topics in their classes.

> I think certainly if engineering faculty are able to talk about ethical dilemmas they faced, that would be the ideal because then it says that, 'ok this is something that you're going to face in your career and you need to be prepared to face these kinds of things.'

Another interviewee expressed a similar opinion in that engineering educators ought to teach ESI because students will "see that it relates more to what they'll be doing." Engineering professors can also link ESI and technical material to demonstrate the interconnectedness of the two. An example of this perspective is that students:

> must see engineers applying ethics because otherwise you get the message that engineers don't think about it and they just wasted a semester thinking about philosophy. So it absolutely has to be applied by engineers in context.

Industry Experience

Beyond their connection to technical content, some interviewees noted that engineering instructors should teach ESI due to, and in the context of, their industry experience. Relating ESI to professional experience can make the instruction more authentic and demonstrate in concrete terms how ethical dilemmas appear in engineering work. An interviewee who worked in manufacturing and automated equipment design before and after receiving her PhD noted how her experience influenced her teaching and its impact on her students.

> Students always like you stories from real life…it's much more impactful to say this happened to me while I was working than to, you know, pull a case study from ASCE that's been all, you know, cleaned and sanitized and what have you. So, yeah, so, just being able to share personal experiences and personal challenges. And I think that all, it also kind of helps the students…just kind of makes it more personal. I think that when I can be more genuine with my class, it makes it more impactful to them.

Another interviewee who is chair of a civil/environmental engineering department with five of its six faculty members holding profession engineering licenses noted that students have positive receptions to this perspective because it relates to what they might encounter after graduation.

> If you have a faculty member who has done professional work or you have a professional engineer from industry who is working as an adjunct, that's looked upon different than someone from the history department who students perceive as not really ever having a job.

Although not all engineering faculty have industry experience, those who do can leverage this experience in their ESI instruction. Personal stories and connections to the real world provide an impactful learning experience for student since most of them will enter industry after graduation.

Interdisciplinary Collaboration

Eight of the interviewees discussed the importance of collaborating across disciplines to teach ESI. Engineering ethics is the confluence of a range of fields including psychology, sociology, and philosophy in addition to engineering [16]. The multidisciplinary nature of ESI thus lends itself well to collaboration between various fields. Engineering ethics involves both technical knowledge and theoretical background and not many single educators are entirely confident or trained in both realms. Interdisciplinary collaboration thus allows the skills and perspectives to complement each other. The interviewee with a philosophy background has worked with engineering professors and industry veterans to develop ESI curriculum for engineering students and described the importance of this relationship.

> I think it's really that simplistic idea of shared expertise, it's the most powerful way to engage and teach, it's just really sometimes hard to do because you have to build effective collaborations, partnerships…. A lot of philosophers don't want to talk to engineers and a lot of engineers don't really think philosophers know anything.

The interviewee with a background in ethics who teaches biomedical and software engineering graduate students noted the importance of working across disciplines to ensure that students are exposed to different perspectives in multiple contexts. In working with engineering faculty, he found that they welcomed his expertise.

> They also really emphasize the fact that they want ethics courses taught by people who are ethicists who have that PhD in ethics or philosophy or something, some type of much deeper understanding of ethics, because the engineering faculty are very very focused on what they do and they know there are ethical issues but they also know that when you're an engineer, you do what you're supposed to, you work within your specialty, and if ethics is not your specialty, then it's something that you want to raise in your course.

Recognizing the bounds of one's own expertise and looking for collaborations to complement it can provide a rich and balanced experience for students. An interview at a private baccalaureate college with an arts and sciences focus who teaches an introductory engineering course noted that the university itself was more conducive to such collaboration. He worked with educators in biology and writing to develop an ethics assignment for the first-year engineering students and tailor a course in the philosophy department specifically to engineering.

> On a campus like this, barrier between department silos can be easier to cross… we are able to work with the philosophy department to develop a course in ethics for our engineering students as opposed to someone in the engineering department teaching that course and we really value those sorts of opportunities for students to take a course in ethics from someone in the philosophy department.

The interviewee in the macroethics through the curriculum program worked with engineering departments across the campus to help develop it. Integrating ESI throughout the undergraduate experience required buy-in from instructors of engineering science, design, and humanities courses because all three represent the main components of the curriculum.

> Yes, it involved people from engineering, people from my department, which is liberal arts and international studies, and other parts of campus collaborating to shape a minor curriculum that was innovative but also really, really filling in some critical gaps in

student's education because those aren't typically concepts and forms of awareness that exist in a traditional engineering education curriculum.

Interdisciplinary collaboration requires willingness from educators within and outside of engineering. If those partnerships can be formed, the approach offers a complement of perspectives that is true to the study of ESI itself.

Course Characteristics

Interviewees discussed specific course types and their limitations and affordances for teaching ESI, as shown in Table 5.

Table 5: Course characteristics sub-codes

Sub-code	Definition	Frequency (n of 82 segments)	Frequency (% of 34 individuals)	Kappa
Standalone course	Advantages or disadvantages of teaching ESI in a standalone ethics course are mentioned	21	50	0.93
Core engineering course	Advantages or disadvantages of teaching ESI in a core technical engineering course are mentioned	19	38	0.76
Requirement	Advantages or disadvantages of a required ESI course are noted.	7	21	0.54
Elective	Advantages or disadvantages of teaching ESI in an elective course are noted	7	18	1.00

<u>Standalone ethics</u>

The interviewees voiced a spectrum of perspectives on the merits and limitations of teaching ESI in standalone courses. The interviewee who teaches in the philosophy department commented that a dedicated course provides the opportunity to establish theories and frameworks that can be applied to case studies and discussions. This approach enables him to scaffold ethical reasoning with ethical awareness and motivation to create an impactful learning experience for students.

> Selfishly, but also with good backing from the literature, I think the most effective way to teach ethics is through an engaged class, an engaged seminar. I understand the limitations and I understand that's not possible, or at least not feasible in a lot of cases but there's good evidence that's the most effective way to teach ethics.

An interviewee who teaches an elective course on ethics and risk open to all engineering students at a public doctoral university with highest research activity [26] noted that course is effective but limited in the number of students that it reaches. Enrollment is based on self-selection and class size is kept small (8-30 students) to enable discussion.

> I'm not saying there's only one way to do it, I just know that the way we're doing it is very effective but we're not reaching a lot of students… at best we'll reach 60 students a year.

The interviewee who teaches a required one-credit course for all engineering students noted that the breadth of ESI demands a standalone course

> To cover engineering ethics well, we need a dedicated course, I think we need at least one credit hour dedicated to engineering ethics because there is so much ground to cover.

However, other educators saw standalone courses running the risk of isolating ESI from the rest of the engineering curriculum. Faculty and students might perceive ESI as outside the purview of engineering, and this course structure can reinforce that idea. An interviewee who is the chair of chemical engineering and whose department does not offer a standalone course but instead integrates it across the curriculum, explained the reasoning, “you can’t compartmentalize it into just one class, like ‘ok, now we’re learning ethics and now we can ignore it.’ It’s got to be part of life.” Another interviewee who teaches professionalism and ESI in a required one-credit course at a religiously affiliated institution commented, “I think for ethics education to thrive, we have to integrate it through the four year experience in classes that don’t have the word ‘ethics’ in it.”

<u>Core engineering course</u>

Instead of teaching ESI in dedicated courses, some interviewees advocated for its incorporation in core engineering courses. Like EAC, this sub-code pertains to including ESI in technical courses but this sub-code relates more to the course description than the overall curricular approach. Engineering courses afford an important opportunity to integrate ESI because these courses are the most significant part of the curriculum in terms of students’ time and attention.

> Ethical development - if it only happens in some pockets it sends a certain message, but we know from past research that the students tend to have the knowledge hierarchy, where engineering sciences are on top, engineering designs below that, their courses like foundation courses in chemistry and physics below that, and then humanities and social sciences even below that. Well, given that hierarchy, if we don't put some sort of macroethical dimension inside engineering sciences, we’re doing students a disservice.

Students tend to prioritize their core engineering courses and including ESI in those settings can tap into their interest and focus. These courses also enable instructors to tie the technical, ethical, and social together.

> The truth is the technical influences the social and vice versa. The interplay in the huge majority of engineering science courses is invisible. And - and if we perpetuate the system we have now, where we don't make the social and technical interplays visible within the engineering sciences, what we’re doing is graduating entire generations of engineers who go out into industry and don't realize these two things interplay and interplay in ways that we need to pay attention to.

Outside of the classroom, the technical and social dimensions of engineering are not neatly parsed. This separation reinforced through the curriculum does not prepare students to consider both sides together. A chemical engineering professor who teaches elective courses on sustainability at a public doctoral university with higher research activity noted the importance of integrating core concepts and their implications.

> Engaging students to explore the broader impacts of that engineering content, the social impacts, the environmental impacts, political implications, most of the students realize

> those are impossible to partition so trying to introduce students to that holist theory rather than just putting the blinders on and crunch numbers.

The interviewee developed an intervention that explores the political, social, economic, environmental, and technical dimensions of hydraulic fracturing. The activity was initially piloted in the sustainability elective then completed by students in fluid dynamics as a way to bring more macroethical issues into core courses.

> I've always been fascinated with the lack of, I don't want to say ethics in general, but social justice issues and environmental issues within engineering and so whole-heartedly intending to incorporate these issues into core classes, like fluid dynamics, is interesting to me and having these technical elective courses, sustainable energy for example, I feel is a good test bed…now integrating fluid mechanics problems into the intervention so as to cover both the fundamentals that need to be covered as well as their broader impacts.

Whether a discussion in class is dedicated to covering the implications of a technical concept, like the Dakota Access Pipeline in a fluids course, or students are asked to reflect on their calculations, like the power needed for a pump calculation, core courses allow instructors to achieve multiple learning outcomes through a contextualized class.

Requirement vs. Elective

In the United States, 80% of engineering graduates are not required to take an ethics course [3]. Programs that mandate ethics-focused courses are the minority and thus most engineering departments take a different approach to achieving student outcomes related to ESI. Elective courses can be advantageous since students choose to take them and thus have greater interest, which is related to motivation [19]. An interviewee who has taught both required and elective ethics courses noted the difference in student reception between the two.

> From the students point of view, I've never had any problems because these are elective courses… but I think on the whole they certainly recognize the value so I've never gotten any pushback. The computer ethics course, that's a required course, so the students had to be there was motivation was much lower, expectations were lower as well.

When students self-select into courses, they are predisposed to higher engagement [27, 28]. Lack of student interest and emotional engagement can be challenge for educators teaching ESI to engineering and computing students [20, 29]. Elective courses also provide the opportunity for a deep dive into ESI that might not be available elsewhere in the curriculum. The chemical engineering professor who teaches sustainability electives noted how his course filled a void.

> Some argue that these courses like mine are superfluous and that these students should be getting this information through the standard curriculum, there's no need to have a separate course on this things… I don't disagree with those colleagues, if we were doing it right there would be no need for the ancillary elective courses focused on sustainable energy and sustainability, if sustainability was integrated across the curriculum, there would be no need… but engineering curricula are very jam packed with technical content.

One drawback of teaching ESI in elective courses is that not all students will have the time or interest to take them. A biomedical engineering professor who helps organize weekly seminars for graduate students commented that participation is low for those who are not required to attend.

> The main challenge I see right now with that is at least currently, those sessions are open for all of the grad students and post-docs in the department but typically they don't take advantage of it. Usually only the people who are required to be there, will be there with a few exceptions.

The merits and limitations of teaching ESI in elective or required courses must be weighed and tailored based on curricular opportunity, faculty availability, and student interest.

Summary and Conclusions

This study explored the insights of faculty members regarding effective settings and curricular strategies for teaching ESI to engineering and computing students. The 34 interview participants represented a range of personal disciplinary backgrounds (inside and outside of engineering), personal teaching experiences, and institutional environments. Therefore, it is not surprising that they voiced a range of opinions on the best ESI educational approaches from curricular and instructional perspectives. Ethics across the curriculum was discussed by 50% of the interviewees. The approach was promoted as a way to build student engagement, reinforce the importance of ESI in engineering, and contextualize ethical and societal issues. This approach aligns with the 4DDD model since it proposes that educating engineers for the 21st century requires broad development, which is achieved through targeting constructs within the social, affective, psychomotor, and cognitive domains that reinforce each other throughout the students' education [19]. Integrating ESI into a range of settings with a variety of pedagogical approaches offers different opportunities to target the constructs that complement one another to support ethical development. However, implementing that curricular strategy requires departmental support, which can be a challenge for educators who perceive a lack of interest and support from their colleagues [20]. Over half of the respondents discussed the importance of teaching ESI in the context of technical courses and/or design projects. Again, this supports the 4DDD model's proposed bilateral relationship between systems thinking and the broader context to increase ethical development. This approach also requires the initiative and commitment of engineering professors but can be less cohesive than EAC. However, teaching ESI in context is advantageous because it helps overcome the barriers of a lack of student engagement and limited curricular space for standalone courses [20, 29]. Micro-insertion, brief and contextualized discussions of ethical and social implications, do not push out technical content while still increasing students' awareness of these issues [30]. Modules can offer a deeper dive into ESI but can be limited in their impact without reinforcement and minimal contact time. These interview comments were congruent with findings that moral education programs of three to 12 weeks are optimal for improvement in moral judgment, as measured by the Defining Issues Test (DIT) [31].

Interviewees discussed a range of opinions regarding effective instruction. Individuals with backgrounds in engineering and non-engineering suggested that, at least in part, ESI needs to be taught by engineering professors. Isolating ESI in other departments can reinforce the pre-conceived notion that ESI is ancillary to engineering. Collaborating across disciplines and being intentional about curriculum design can provide students with a balance of the theoretical nuances and technical applications of ESI. Although such partnerships can be difficult to form, especially on large research focused campuses with disparate department silos, the results show that educators from both engineering and non-engineering backgrounds see the value of such collaborations. A 2017 National Academy of Engineering Report also supported interdisciplinary collaborations for ESI instruction and promoted the strategy as a key to organizational change across the institution [32]. The results suggest that ESI education is not one size fits all; different faculty backgrounds, department environments, and institutional cultures offer various limitations and affordances for curricular approaches. Best practices must thus span a range of contexts that can be readily transferred.

Future work will continue to explore the question of effective settings for ESI instruction. The on-going phase of our broader study involves partnering with a sub-set of the interviewees to explore their teaching practices in-depth. Pre and post student surveys, student focus groups and interviews, student work evaluations, additional faculty interviews, and alumni surveys and interviews are being used to triangulate perceptions of high impact instruction from students, faculty, and alumni. This work also seeks to understand specific cultures and instructor backgrounds more deeply through site visits to determine best practices that could be aligned with common contexts. The research aims to identify exemplars of ESI instruction and disseminate strong models of different settings and approaches.

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