2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #35657

2020 BEST PIC IV PAPER WINNER - Student Perceptions of an Ethics Intervention - Exploration Across Three Course Types

Dr. Madeline Polmear, University of Florida

Madeline Polmear is a postdoctoral researcher in the Department of Civil and Coastal Engineering at the University of Florida. She completed her B.S. in environmental engineering, M.S. in civil engineering, and Ph.D. in civil engineering at the University of Colorado Boulder. Her research focuses on bridging technical and nontechnical competencies to support the professional preparation and ethical responsibility of engineering students.

Dr. Angela R. Bielefeldt, University of Colorado Boulder
Dr. Nathan E. Canney,
Dr. Chris Swan, Tufts University
Dr. Daniel Knight, University of Colorado Boulder

Student Perceptions of an Ethics Intervention: Exploration Across Three Course Types

Dr. Madeline Polmear, University of Florida

Madeline Polmear is a postdoctoral researcher in the Department of Civil and Coastal Engineering at the University of Florida. Her research interests include workforce development and engineering ethics education.

Dr. Angela R Bielefeldt P.E., 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) and Director for the Engineering Plus program. She has served as the Associate Chair for Undergraduate Education in the CEAE Department, as well as the ABET assessment coordinator. Professor Bielefeldt was also the faculty director of the Sustainable By Design Residential Academic Program, a living-learning community where students learned about and practice sustainability. Bielefeldt is also a licensed P.E. Professor Bielefeldt's research interests in engineering education include service-learning, sustainable engineering, social responsibility, ethics, and diversity.

Dr. Nathan E Canney P.E., CYS Structural Engineers Inc.

Dr. Canney conducts research focused 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.

Dr. Chris Swan, Tufts University

Chris Swan is Dean of Undergraduate Education for the School of Engineering and 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 sustainable materials management (SMM) strategies.

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 K-12, program evaluation and teamwork practices in engineering education. His current duties include assessment, team development, outreach and education research for DC Colorado's hands-on initiatives.

Student Perceptions of an Ethics Intervention: Exploration Across Three Course Types

Abstract
This research paper explored student perspectives on a micro-insertion of an ethics and societal impacts (ESI) intervention into three courses, using qualitative data collected in focus groups. An intervention examining hydraulic fracturing from different perspectives (e.g., economic, political, environmental) was incorporated into a required, foundational course; an upper-division technical elective; and a lower-division elective open to all majors. The intervention was the subject of a broader case study that involved separate focus groups with students in each of the courses. The theoretical framing of the study was Vanasupa and colleague's Four Domain Development Diagram, which provides a model for effective learning in engineering education including ethical development. The focus group transcripts were analyzed using thematic coding to explore evidence of the model concepts (e.g., value, interest, and autonomy). Using the constant comparative method, the analysis also sought to understand similarities and differences in student perceptions based on course and student characteristics. Across the three courses, students described the value of self-guided and collaborative learning, understanding engineering in the societal context, and creating a comfortable learning environment. The findings also indicated differential perceptions of the intervention based on if the course was required or elective, where the content was situated relative to other courses in the degree program, and if the relevance of the intervention was clear to students' personal and academic interests. This research provides suggestions for educators designing ESI instruction and considerations of the context in which the instruction is embedded.

Introduction
Calls to improve engineering ethics education have reverberated through industry and government with increasing intensity over the past few decades (e.g., [1], [2]). Engineering programs have responded to the growing recognition of the need to foster students' ethical development and awareness of societal impacts in a variety of ways [3]-[5]. Without consensus on how engineering ethics should be taught or which outcomes the instruction should aim to achieve, different approaches have been implemented with varying perceptions of efficacy [6].

Engineering ethics and societal impacts (ESI) integration strategies include ethics across the curriculum (intentional distribution of content throughout the engineering coursework), standalone ESI-related courses (required or elective), and modules in technical courses. The breadth of these options is represented in the National Academy of Engineering compilation of exemplary educational activities and programs for the ethical development of engineers [7]. The 25 highlighted settings covered a range of topics (not all related to both ethics and societal impacts) and included undergraduate courses, graduate courses, and multiyear programs. The report identified elements characteristic of exemplary education, which included active learning, connection to engineering practice, occurrence across multiple years, inclusion of both microethics and macroethics, creative educational methods, and ability to scale and replicate at other institutions. The report also suggested that the infusion of ethics should include real-life examples and interactive format to address student challenges.

Although more comprehensive approaches like ethics across the curriculum and standalone courses provide deeper coverage and increased opportunity for students to engage with the topics, there are logistical and institutional challenges that make these approaches harder to integrate [8]. Ethics across the curriculum requires widespread faculty support and commitment, including individuals' willingness to coordinate efforts across the degree program and teach ESI in their own courses. Given shrinking credit hours for engineering degrees and an increasing number of topics, it can be challenging to find space in the curriculum for standalone ethics courses [9]. These courses can be offered outside of the engineering department as part of the general education or liberal arts requirement, but this approach can be met with a lack of student engagement if the topics appear disconnected from their engineering preparation [10].

Given these considerations, micro-insertions of ESI have been promoted as an effective approach [11]. Micro-insertion is the integration of ethics in technical courses "without substantial change in the course and in a way students appreciate" [11, p. 722]. Micro-insertions integrate ESI without derailing the syllabus thereby mitigating challenges that confront faculty who have limited curricular space to dedicate to ethics. Micro-insertions can be part of the ethics across the curriculum approach by including small doses of ESI in core courses, which subtly demonstrates that ESI is part of the foundational engineering curriculum. Situating ESI in foundational engineering content also helps students contextualize its importance, which can support their emotional engagement [10]. Although micro-insertions can overcome barriers often cited in engineering ethics, in a recent systematic review of ethics interventions in the United States, micro-insertion was only cited in 8% of the articles. Micro-insertions, as a pedagogical approach, was uncommon relative to other pedagogies; codes of ethics were used in 85% of the articles, case studies were noted in 81%, debates in 77%, and individual written assignments were noted in 54% of the articles [12].

As engineering programs are decreasing the number of credits for graduation [13] while maintaining professional and ethical responsibility as key student outcomes [14],

> It is incumbent upon the engineering community to see that ethical problems, standards of conduct and critical thinking skills are adequately developed within the context of technical courses… engineering educators must face head on the societal and ethical implications of engineering [3, p. 311].

Given that micro-insertions can help engineering educators meet this directive, it is instructive to understand how students perceive such instruction in terms of their ethical learning and development. This research aimed to address this question by exploring student perspectives on an ESI micro-insertion through the lens of designing holistic learning experiences for the 21st century engineer.

Research Questions

This research was informed by the following research questions:

RQ1: What are students' perspectives of an ESI micro-insertion (a hydraulic fracturing intervention) as it relates to their ethical development?

RQ2: How do student perspectives vary across the three settings in which the intervention was integrated?

Theoretical Framework

The framework underpinning this research was the Four-Domain Development Diagram (4DDD) [15]. The 4DDD provides a lens through which to view learning and components of the learning environment as they relate to ethical development. This model integrates social, affective, cognitive, and psychomotor dimensions to guide the development of learning environments for 21st century engineering education. The 4DDD was developed in response to calls to reform engineering education to be more responsive to societal challenges and the broader skillset needed to address them. Motivation is at the center of the model and is fostered through a positive feedback loop between interest, autonomy, and value. This framework postulates that if students enjoy the material (interest), they are more motivated to learn. If students experience a sense of freedom in their learning (autonomy), their interest develops further. If students find the material relevant to their personal goals (value), they are more engaged and therefore more motivated. Understanding the broader context, the connection between what is being taught and its implications for society and self, thus contributes to interest and relevance. These three constructs foster motivation, which is inextricably linked to engagement. Engagement is demonstrated in the model to draw on a combination of cognitive/psychomotor and affective/social domains. Vanasupa et al. summarize the key relationships as "increases in understanding the broader context lead to increases in motivation, which lead to increases in engagement, which lead to an increase in moral/ethical development" [15, p.74].

The framework was chosen for this study because it includes the cognitive and affective domains, both of which are important in ethical development and decision-making. Emotion is an important part of responsible engineering design and technology [16], [17]. The social aspect of the model also speaks to the inherently social nature of ESI since ethical decisions are made in complex organizational contexts that include many stakeholders [18]. Engineering ethics has traditionally been taught with an individualistic approach that emphasizes the action and autonomy of a single actor; however, this approach has been criticized for not accounting for the context in which engineers work and their broader role in society [19]. The framework was also appropriate for this study because it relates moral and ethical development with understanding the broader context, which mirrors both the microethical and macroethical dimensions inherent in ESI [3].

The 4DDD offers guidance for designing instruction that supports engineering students' holistic development, part of which is moral and ethical development. Micro-insertion is one instructional strategy that has been advocated in engineering ethics education. This research used a case study approach to understand if an ethics micro-insertion demonstrated the potential to support moral and ethical development by understanding if students' perception of the instruction alluded to constructs in the framework.

Project Context

This study was embedded in a National Science Foundation-funded project that explored the broad landscape of ESI education in the United States and identified exemplary practices. The project first employed a quantitative approach to understand educators' practices and perspectives related to ESI (n=1448). For more information, see [20]-[23]. The second phase used in-depth interviews with select survey respondents to gain further insights into the course in which they teach ESI, the pedagogies they employ, and the influences on their instructional decision-making (n=37). Additional information on this phase has been published [24]-[26]. The third phase further reduced the number of participants to explore a sub-set of ESI instructional settings in greater detail (n=11). This part of the study was designed to explore potentially exemplary ESI settings through a mixed methods case study approach. The case studies included follow-up interviews with the faculty partner, evaluation of student assignments with a rubric, student surveys, and alumni surveys. A sub-set of the case studies (n=8) also included a site visit with observations of the instructional setting and focus groups with the students. The phases and methods of the project are described to provide context for the present study and demonstrate how participant selection has funneled over the course of the project. Although a range of participants and data collection methods have informed the broader project, only one case study site and data collection method are included in the present study, which are described in the following section.

Methods

Setting and Intervention

The present study focused on one case study site. This site was selected for analysis because it uniquely included three courses. While the other case study sites were bound as a single instructional setting, this site was defined around an instructional intervention, which was embedded in three different course types. The courses were all offered through the chemical and biological engineering department and included a required, foundational course (Chemical Engineering Fluid Mechanics, n= 40 students); an upper-division technical elective (Sustainable Energy, n=37 students); and a lower-division elective open to all majors on campus (Energy and Sustainability, n=65 students). The intervention was developed and taught by a team of two chemical and biological engineering faculty members at Montana State University. Detail on the development and implementation of the intervention has been published [27], [28]. The intervention was taught on the same day in all three classes (in October 2017 approximately six weeks into the semester). The intervention was not students' only exposure to ESI; it was one element in a growing initiative towards ethics across the curriculum. The chemical and engineering department integrated ESI in multiple core courses including first-year introduction, junior design, and senior capstone design.

The intervention was an in-class activity that explored hydraulic fracturing from different perspectives. The intervention followed the same format in all three courses. Each 75-minute class period began with an introduction of the activity and series of pre-activity questions for the students to complete. The questions related to students' understanding of hydraulic fracturing, support of hydraulic fracturing, willingness to lease land to an oil company if resources were discovered on their property, and sources of their background information on the topic. The instructor then showed two videos that were approximately five minutes long and explained that they represented different perspectives: one developed by an oil company with an industry bias and one from a science literacy group that had an environmental bias.

After watching the videos, students were split into five groups that were assigned a different perspective: science and engineering, economic impact, environmental impact, societal impact, and political impact. The students were instructed to use their phones or laptops to individually research hydraulic fracturing through their assigned lens. Following their individual research, the students in each group discussed their findings and developed consensus statements that were reported out to the class. The whole class engaged in a discussion around these different perspectives and groups were invited to ask each other questions. At the end of the period, students completed the same series of questions regarding their opinions on hydraulic fracturing.

Data Collection
One member of the research team (the first author) observed the intervention in all three courses. The next day, the researcher led three focus groups with student volunteers from each of the courses. Each focus group lasted 25-35 minutes. The focus groups were audio-recorded and transcribed. The questions were designed to elicit students' feedback on the intervention (including what was effective, what could be improved, and if the pace of the activities was appropriate), their engagement with ethical issues in the class, and the broader perspectives on the role of engineers in society. The focus group protocol is included in the Appendix to show how students were prompted in the discussion.

Participants
Participants were recruited through an electronic flyer that the research team developed and the instructor distributed to the classes to advertise the focus groups. The flyer was distributed prior to the intervention and students were reminded about the focus group during the class period. Students were offered a $10 Amazon gift card for participating. Participant information, including gender, major, and year of study, is displayed in Table 1. Participation rates varied from 8% (Fluid Mechanics) to 19% (Sustainable Energy); the low participation rate is a potential limitation since participants might not be representative of the rest of the students in each course.

Table 1: Participant information

Course	Female (n)	Male (n)	Major (n)	Year (n)
Fluid Mechanics	0	3	ChemBio Eng (3)	3rd (3)
Sustainable Energy	1	6	ChemBio Eng (7)	3rd (1), 4th (6)
Energy and Sustainability	2	3	Political Science (1), Economics (1), Business (1), Environmental Science (1), Sustainable Food and Bioenergy Systems (1)	1st (5)

Data Analysis
This research employed thematic analysis [29] that was completed using Dedoose qualitative analysis software [30]. The focus group transcripts were analyzed deductively with constructs of the 4DDD model serving as *a priori* codes. These constructs from the 4DDD model served as anchor points to understand how students' perspectives mapped to the theoretical framework as a way of understanding the potential for a micro-insertion to contribute to students' ethical development as conceptualized in the framework. It is not expected that a single intervention is responsible for ethical development. Understanding and enacting ethics are processes that take time to cultivate and internalize. However, there are a number of learning outcomes within engineering ethics education (i.e., sensitivity/awareness, judgment/imagination, and

courage/commitment) that can be targeted in a single intervention [12]. The codes used and their definitions (modified from [15]) are displayed in Table 2. As indicated in Table 2, ethical development in the context of the 4DDD includes ability to identify ethical issues (which can be conceived as sensitivity/awareness) and decide on ethical actions (similar to judgment/imagination). The table also indicates if there was evidence of each code for the three courses based on if any student discussed something that was coded to the element of the 4DDD.

Table 2: Deductive codes from the 4DDD and evidence from focus group of students from the courses (F = Fluid Mechanics, E = Sustainable Energy, S = Energy and Sustainability, No = not observed)

Code	Definition	Course
Mastery	Competence, proficiency in understanding and applying knowledge	No
Broader context	Understanding of the subject's societal implications	F, E, S
Engagement active learning	Student involvement in learning	F, E, S
Ethical development	Ability to identify ethical issues and decide on ethical actions	F, E, S
Relatedness	Feeling of belonging and support in the learning setting	F, E
Systems thinking	Ability to see connections and see the whole instead of individual parts	F, E, S
Interest	Intrinsic enjoyment	E, S
Autonomy	Personal control and freedom	S
Value	Relevance to personal goals and interests	E, S
Motivation	Internal drive to learn	E, S

The 4DDD framework focuses on student-centered development to inform the design of effective learning opportunities. Thus, the analytical approach was grounded in the perspectives of individual students within the three learning contexts. Some of the constructs (and thus codes) are personal, such as interest and value, while others speak to the social aspects of learning in the instructional setting (e.g., relatedness). In this way, the analysis attempted to understand the social interaction and environment.

After the first examination of the transcripts in which the deductive codes were explored, the transcripts and codebook were revisited to explore patterns across the coded segments and to develop themes. These themes are presented in the Findings and Discussion.

Limitations

The focus groups were limited to the perspectives of those present. Since participation was voluntary, it cannot be assumed that the voices were reflective of the rest of the students in the courses. Recruitment in qualitative research has been linked to interest in the subject matter [31] so the focus group participants might have been more interested in ESI. The 4DDD was chosen as the theoretical framework as a way to interpret the potential of a micro-insertion to contribute to ethical development through its conceptualization of instructional design for holistic development. However, there are a number of models and theories related to effective learning. This study does not purport that certain learning frameworks or pedagogies are the only approaches for understanding a subject as nuanced as engineering ethics. Furthermore, this study was limited to a single intervention in each of the three courses. The analysis thus does not capture the whole picture of how students attain ethics-related outcomes in their undergraduate experience, which included additional courses and likely also includes co-curricular activities [6].

Findings and Discussion

This section presents and discusses the findings by research question; first, exploring students' perspectives of the intervention related to their ethical development through the lens of the 4DDD and second, comparing perspectives across the three course settings. As noted above, after the initial analysis using the *a priori* codes, the data were reexamined to extract patterns. This thematic analysis drew connections between the codes and transcripts to better understand how the 4DDD constructs manifested and interacted in the data. This second phase of the analysis informed the development of the themes presented in this section.

RQ1: Student Perspectives of the Intervention Related to Ethical Development

Looking across the coded segments, thematic patterns emerged that elucidated connections between the intervention, learning environment, and understanding of ESI. The most salient patterns across the three course types related to 1) Facilitating Self-guided and Collaborative Learning, 2) Understanding Engineering in the Societal Context, and 3) Creating a Comfortable Environment.

<u>Facilitating Self-guided and Collaborative Learning</u>

This theme from the focus group data was informed by findings related to "autonomy" and "relatedness." Students in all three focus groups discussed how the format of the intervention facilitated learning through opportunities to conduct individual research and discuss with their peers. Although the five groups were assigned and thus students did not have control over the perspective that guided their research, they had the autonomy to find their own sources of information and decide what was the most pertinent to their understanding of hydraulic fracturing through that lens. Having students seek out sources and identify issues could also increase their awareness of the ethical implications of hydraulic fracturing and this sensitivity contributes to ethical development. This sense of freedom was a departure from traditional classroom learning in which the instructor decides what is be taught. One student from Energy and Sustainability noted,

> I think the activity was helpful because instead of like [instructor] or someone telling us a bunch of stuff, we were actually able to find out information ourselves. So we got to see firsthand research, and I think the fact that we were able to discuss it with other people made it a lot more, I guess easy [to] be engaged in and easy to understand.

This comment reflected the causal relationship between autonomy and active learning [15] since the student found benefit in feeling control to guide learning, which in turn increased engagement in the activity. Another student from Fluid Mechanics similarly remarked the impact of active participation on learning: "I don't learn very well from lecture and watching people solve problems. I think people learn better from actually trying things out themselves." A student in Sustainable Energy also noted that this active involvement supported retention, "I feel like I remember the information I researched in my own group… It's more helpful to do the research yourself." Students noted greater engagement by taking a more active role in their learning, conducting research, and guiding the classroom discussion based on their findings.

After conducting individual research, the students in each group developed consensus statements. As the student from Energy and Sustainability noted, the opportunity for discussion supported engagement. This aspect of the intervention encouraged the students to reconcile their own perspectives with those of their peers. According to the moral theory that underpins the 4DDD, moral development occurs when an individual learns to address conflict between personal values and broader issues. The intervention provided an opportunity for this development by having students work collaboratively to reconcile their own findings with their peers' to formulate statements that represented their groups' perspective.

Understanding Engineering in the Societal Context

This theme drew on the "broader context" code and how it interacted with "value." Students in all three focus groups expressed that the hydraulic fracturing intervention contextualized the impact of engineering. Irrespective of discipline, students described the benefit of exploring the broader implications of their work. As an example, a student in Energy and Sustainability noted, "I just feel like it's a good perspective to have in whatever you're doing to think about the other more broad impacts of something." Engineering is often taught in a way that divorces technical content from its societal impact and this socio-technical dualism can separate students from their societal responsibility [32]. However, ethical responsibility is imperative in a profession that affects every aspect of modern life [1]. Reinforcing this sense of responsibility throughout the curriculum helps increase students' awareness and judgment, which supports their ethical decision-making in practice [33]. One student in Fluid Mechanics noted that the intervention "show[ed] how broad of an impact the technology we might be working on in the future can have on the country and the world sometimes." The hydraulic fracturing activity helped this student understand the potential implications of his future career and this was an important outcome since he planned to pursue employment in the oil industry.

The narrow technical focus of individual courses in the engineering curriculum can obscure connections between, and implications of, engineering concepts. One student described that Sustainable Energy as a whole course supported the broader integration of engineering concepts and their practical applications.

> It helps put all the other classes into the wider focus and give more perspective… It helps us see the connections between everything, and Sustainable Energy definitely helps with that.

An understanding of the broader context has a mutually reinforcing relationship with ethical development since situating students' work outside of the academic environment promotes motivation and engagement, which in turn, supports their ability to resolve conflicts between their personal and professional values [15].

Creating a Comfortable Environment

This theme was extracted from reexamining the transcript segments related to "relatedness" and their overlap with "motivation" and "engagement." The environment of a classroom can have a significant effect on learning [15]. Although hydraulic fracturing is a politically and socially divisive issue, students in the three courses remarked that the classroom environment facilitated positive and fruitful discussion. It is worth noting that all three courses had 37-65 students and although they employed some degree of active learning throughout the semester, they were primarily lecture format.

The activity was designed to emphasize fact-finding and reporting. This format established a feeling of objectivity. A student in Sustainable Energy noted that by starting the class period with videos from both the pro-industry and pro-environment perspective fostered an open environment: "I think the fact that [instructor] showed the two videos with sort of biases in different directions opens it up, makes it more comfortable." Instead of establishing an inclination toward one side or the other, the activity was designed to show there are different perspectives on the issue. Another student in Sustainable Energy described the classroom as "definitely a comfortable environment." Although the intervention was structured to focus on fact-finding, students noted that they would have been comfortable expressing their opinions if the discussion shifted away from objectivity. A student in Fluid Mechanics noted,

> I feel like if it did get to that, where somebody was expressing their opinion and debating about something, I feel like it was a casual enough situation where that wouldn't have been too much of an issue.

This is an important aspect of instructional design to foster ethical development since "creating a supportive learning environment increases students' sense of relatedness which increases one's motivation and ultimately increases student engagement" and engagement directly feeds into ethical development [15, p.71]. Although it is important to create a supportive environment in the classroom, this might not be reflective of the settings in which engineers work. Engineering organizations are complex contexts that must negotiate different stakeholder values and conflicting priorities so it is far more challenging to create objective discourse in professional settings. The disconnection between the classroom setting and professional practice as it relates to ethics-related discussion and decision-making could be explored in future research.

RQ2: Variations across the three settings

Previous research has reported different curricular approaches in ethics instruction [3], [12], [33] and varying perception of efficacy based on course setting such required versus elective courses and foundational engineering versus non-engineering courses [25]. The second research question in this study sought to understand if there were apparent distinctions in students' perspectives of the intervention based on the course in which they participated. It is important to note that a number of factors affect the setting. Structural characteristics, such as class size, topic, and placement in the curriculum, and student characteristics, including discipline and year of study, can play into the dynamic of the learning environment and were considered in this analysis. Reexamining the transcript segments and deductive codes suggested thematic differences between the settings that influenced students' experience and reception of the hydraulic fracturing intervention.

Consideration of Elective versus Required Course

This theme drew on the “autonomy”, “interest”, and “value” coded segments since their interaction informed varying perceptions across the three settings. As indicated in the 4DDD, students who self-select into a course (and thus have autonomy over that decision) presumably have greater interest and motivation than they would in a required course. This dynamic can drive their perceptions of courses. Students’ evaluations of a course differ significantly based on whether the course was required or elective with students rating quality, enjoyment, and usefulness of elective courses higher than required courses [34]. As shown in the 4DDD, interest and motivation support ethical development so this reinforcing relationship can impact learning and decision-making related to ESI.

In this three-course analysis, Energy and Sustainability and Sustainable Energy were both electives and Fluid Mechanics was required for all chemical and biological engineering majors. All three of the students in the Fluid Mechanics focus group noted that they were taking the course to fulfill the degree requirement. When asked about their motivation for taking the course or what they hoped to get out of it, one student in Fluid Mechanics commented “it's pretty much because you have to as part of the program.” This perspective contrasted with the motivation that students in Energy and Sustainability expressed. The focus group participant studying political science described the choice to sign up for the course as,

> For me, wanting to advocate for climate change, I think just learning about different alternatives that that can be accomplished. I think that's really been helpful and eye opening.

The course was viewed as a way to broaden exposure with the ultimate aim of supporting her future aspirations related to environmental advocacy. A student majoring in business also expressed that the course was seen as a way to connect personal and professional interests at the nexus of business and sustainability: “I just was interested in sustainability and how to make things sustainable… It just for me personally makes me want to create a sustainable business.” A participant who was an economics major noted a similar motivation in taking the course,

> A lot of a lot of economic questions are ‘how can we do this plus be sustainable?’… You're looking the money but you need to also think about more indirect impact.

As suggested by these comments, students in Energy and Sustainability expressed greater value in learning about ESI because they saw the connection between sustainability, their interests, and their goals.

All of the students in Fluid Mechanics and Sustainable Energy were chemical and biological engineering majors. Although their discipline was the same, students in the elective course described different perspectives on their future professional responsibility from students in the required course. A student described the pathway to his major as,

> I kind of just chose chemical engineering to, like I saw what a change you can have on the world. I found that inspiring and part of the reason why I chose it. To create more social good.

Aligned with this motivation, he chose to take Sustainable Energy because he is interested in a career in renewable energy. Other students in the Sustainable Energy focus group expressed being driven by a similar sense of societal responsibility.

> Chemical engineering oftentimes is the source of these disasters and accepting that responsibility and taking the proper measures to mitigate those risks while still recognizing that as a whole our society needs these products. So trying to produce them in the most sustainable and safe way possible. I view it as an increasing responsibility because of all the extra oversight that the public is gaining through social media.

Another Sustainable Energy student echoed, “everybody has a social responsibility.” This shared sense of responsibility contrasted with the perspective described in Fluid Mechanics that ethical responsibility is a personal judgment, not a professional requirement.

> I mean some people might hate the petrochem industry and burning hydrocarbons and so they would never go work in an industry. Other engineers like us might have a job and make money and I'll do whatever the boss tells me to. It's kind of up to you.

Another student in Fluid Mechanics similarly described that using engineering for humanitarian aims is a personal choice and should not be considered an engineer’s duty.

> I mean there's always organizations like Engineers Without Borders where you know you go work in the more impoverished areas to help improve their technology and infrastructure. If that's something that you have the availability to do, I don't think that you necessarily have a responsibility to do that. But if you feel like it's something you should do, then go ahead and do it I guess.

Herkert argued, “a key concept in engineering ethics is the notion of ‘professional responsibility’” [3, p. 304]. These findings suggest a potentially impactful dynamic between students’ ethical development and sense of professional responsibility drawing on their interest and motivation. Future research could explore how a students’ interest and motivation to pursue engineering is informed by, or influences, their sense of professional responsibility and what implication that has for their learning about ethics.

<u>Placement in, Relationship to, the Degree Program</u>

Comparison between the focus groups indicated that placement of the ESI instruction in the degree program can be impactful. Students in Sustainable Energy, who were mainly in their fourth year, were more sensitive to the connection between ESI and chemical engineering than students in Fluid Mechanics, who were in their third year. By fall semester of their fourth year, students in Sustainable Energy had taken two courses that also directly discussed ethics. A student in Sustainable Energy noted that his understanding of professional responsibility developed in Reactor Design and Multidisciplinary Design, both of which are required in the chemical engineering degree program.

> I think that was something I kind of learned along the way because like a lot of the class we've taken like Reactor Design, like Multidisciplinary Engineering like they had units on like ethics and like in Reactor Design we watched some videos of like chemical plants kind of blowing up and like what caused them, like what the outcomes were and so like I never really thought about it before taking those classes. Like how big a responsibility it is to sign off on something like that.

The students in Fluid Mechanics had not yet taken those two courses or were in the first month of taking them and thus had not been exposed to the ethics units. They expressed that the hydraulic fracturing intervention was their first exposure to ESI. A focus group participant from Fluid Mechanics said, “it’s probably the first time” a class included ethical or societal issues in engineering and continued, “it’s not something that is brought up a lot.” The 4DDD demonstrates that systems thinking and understanding the broader context supports students’ ability to see connections and conceptualize engineering as the sum of its parts.

<u>Need to Explicate the Relevance</u>

When asked how the intervention could be improved, students in both Fluid Mechanics and Sustainable Energy described wanting a more explicit understanding of its relevance. A student in Fluid Mechanics commented, “I think maybe in a fluids-specific, aspect, it [the intervention] may not have been extremely relevant.” Although fluid mechanics are fundamental to hydraulic fracturing operations, students struggled to understand how the intervention connected to the course material. The student went on to suggest, “I think it would be a good idea to maybe have a quick discussion at the start of class how it connects to what we're going over in class.” Similarly, a student in Sustainable Energy suggested the intervention would benefit from “a primer of some sort beforehand…[so] you have a better idea of how it fits into everything.” The value, or relevance to fulfilling personal goals, that a student assigns to a topic directly influences their motivation [15]. As a result, if students do not have a clear idea of how the topic fits into the course, their academic plan, and future career, they can struggle to fully engage with it. This lack of emotional engagement resulting in considering the topic irrelevant and uninteresting has been cited as a challenge in engineering ethics education [10].

Students in Energy and Sustainability did not express a disconnection between the intervention and course material nor the need to explicitly situate it.

Implications and Conclusions

In recent years, there have been external pushes from industry (e.g., [35]), accrediting agencies (e.g., [14]), and government (e.g., [36]) to increase the ethical development of engineering students and their exposure to the broader impacts of engineering. Despite these drivers, engineering programs are challenged by a lack of curricular space that constrains their ability to integrate ethics in standalone courses. One strategy to overcome this barrier is to teach ESI via micro-insertions [11]. Thoughtful integration of micro-insertions into a variety of courses across the curriculum (including core engineering and engineering science courses) with deeper engagement in some locations (typically capstone design and/or full ethics courses) may be an effective model for ethical development. This research aimed to understand the impact of this pedagogical approach on students’ ethical development through the lens of the 4DDD model.

These findings offer implications for engineering educators who are designing learning activities and environments to foster ethical development. Constructs from the 4DDD can be integrated to create interventions that facilitate ethical development via active learning, understanding the broader context, and systems thinking and by tapping into students' value, interest, and autonomy. With the hydraulic fracturing intervention, granting students the autonomy to conduct their own research and guide peer collaboration fostered interest and engagement. Situating the activity in the broader context of engineering in society helped students appreciate their professional responsibility and understand the role of engineering in a systems perspective.

The focus group analysis also indicated that the impact of an intervention is partially dependent on the context in which it is embedded. Engineering educators should be mindful of the course characteristics (elective or compulsory and placement in the broader degree program) and student characteristics (major and year of study) when considering the transferability of ESI interventions. These factors also come into play when considering the objective or intended impact of the instruction. Ethics instruction can serve different learning goals such as awareness (sensitivity to ethical issues students may encounter), decision-making (ability to take ethical actions), or commitment (motivation to be ethical) [12]. Micro-insertions can be effective for cultivating ethical awareness but might not achieve outcomes related to ethical judgment and will-power. Future research could apply the 4DDD to other settings and interventions to understand the potential to contribute to students' ethical development across their undergraduate experience.

Acknowledgements
This material is based on work supported by the National Science Foundation under Grant Nos. 1540348, 1540341, 1540308, and 1755390. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. The authors thank Drs. Paul Gannon and Ryan Anderson for their engagement in the research project.

References

[1] National Academy of Engineering. *The engineer of 2020 visions of engineering in the new century*. Washington DC: National Academies Press, 2004.
[2] Sheppard, S. D., Macatangay, K., Colby, A., & Sullivan, W. M. (2008). *Educating Engineers: Designing for the future of the field*. Jossey-Bass.
[3] J. Herkert, "Engineering ethics education in the USA: Content, pedagogy and curriculum", *European Journal of Engineering Education*, vol. 25, no. 4, pp. 303-313, 2000.
[4] C. E. Harris, M. Davis, M. S. Pritchard, and M. J. Rabins, "Engineering ethics: What? Why? How? And When?," *Journal of Engineering Education*, pp. 93–96, Apr. 1996.
[5] A. Colby and W. Sullivan, "Ethics teaching in undergraduate engineering education", *Journal of Engineering Education*, vol. 97, no. 3, pp. 327-338, 2008.
[6] C. J. Finelli, M. A. Holsapple, E. Ra, R. M. Bielby, B. A. Burt, D. D. Carpenter, T. S. Harding, and J. A. Sutkus, "An assessment of engineering students curricular and co-curricular experiences and their ethical development," *Journal of Engineering Education*, vol. 101, no. 3, pp. 469–494, 2012.

[7] National Academy of Engineering. *Infusing ethics into the development of engineers exemplary education activities and programs*. Washington, D.C: National Academies Press, 2016.
[8] J. Li and S. Fu, "A Systematic Approach to Engineering Ethics Education", *Science and Engineering Ethics*, vol. 18, no. 2, pp. 339-349, 2010. Available: 10.1007/s11948-010-9249-8.
[9] J.A. Cruz and W.J. Frey, “An effective strategy for integrating ethics across the curriculum in engineering: An ABET 2000 challenge,” *Science and Engineering Ethics*, vol. 9, no. 4, pp. 543-568, 2003.
[10] B. Newberry, "The dilemma of ethics in engineering education", *Science and Engineering Ethics*, vol. 10, no. 2, pp. 343-351, 2004.
[11] M. Davis, “Integrating ethics into technical courses: micro-insertion”, *Science and Engineering Ethics*, vol. 12, no.4, pp.717-730, 2006.
[12] J. Hess and G. Fore, "A systematic literature review of US engineering ethics interventions", *Science and Engineering Ethics*, 2017.
[13] J. S. Russell and W. B. Stouffer, “Survey of the National Civil Engineering Curriculum,” *Journal of Professional Issues in Engineering Education and Practice*, vol. 131, no. 2, pp. 118–128, 2005.
[14] ABET, “Criteria for accrediting engineering programs”, Engineering Accreditation Commission, Baltimore, MD, 2018.
[15] L. Vanasupa, J. Stolk, and R.J. Herter, “The Four-Domain Development Diagram: a guide for holistic design of effective learning experiences for the twenty-first century engineer”, *Journal of Engineering Education*, vol. 98, no. 1, pp. 67-81, 2009.
[16] S. Roeser, “Emotional engineers: Toward morally responsible design,” *Science and Engineering Ethics*, vol. 18, no. 1, pp. 103–115, 2012.
[17] S. Roeser, “The role of emotions in judging the moral acceptability of risks,” *Safety Science*, vol. 44, no. 8, pp. 689–700, 2006.
[18] E. Conlon, “Towards an Integrated Approach to Engineering Ethics,” In 3rd Internal Symposium for Engineering Education, Cork, 2010.
[19] E. Conlon and H. Zandvoort, "Broadening Ethics Teaching in Engineering: Beyond the Individualistic Approach", *Science and Engineering Ethics*, vol. 17, no. 2, pp. 217-232, 2010.
[20] A.R. Bielefeldt, M. Polmear, N. Canney, C. Swan, and D. Knight. “Ethics education of undergraduate and graduate students in environmental engineering and related disciplines,” *Environmental Engineering Science, 35*(7), 684–695, 2018. https://doi.org/10.1089/ees.2017.0308
[21] A.R. Bielefeldt, M. Polmear, D. Knight, C. Swan, and N. Canney. “Intersections between engineering ethics and diversity issues in engineering education.” *Journal of Professional Issues in Engineering Education and Practice, 144*(2), 04017017, 2018. https://doi.org/10.1061/(asce)ei.1943-5541.0000360
[22] A.R. Bielefeldt, M. Polmear, D. Knight, C. Swan, and N. Canney. “Disciplinary variations in ethics and societal impact topics taught in courses for engineering students,” J*ournal of Professional Issues in Engineering Education and Practice*, *145*(4), 2019.
[23] A.R. Bielefeldt, N. Canney, C. Swan, M. Polmear, and D. Knight. “Microethics and macroethics education of biomedical engineering students in the United States.” *Ethics in Biology, Engineering and Medicine: An International Journal, 7*(1–2), 21–41, 2016. https://doi.org/10.1615/ethicsbiologyengmed.2017018790

[24] M. Polmear, A.R. Bielefeldt, D. Knight, C. Swan, N.E. Canney, “Faculty Perceptions of challenges to educating engineering and computing students about ethics and societal impacts, “ in American Society for Engineering Education Annual Conference & Exposition, Salt Lake City, UT, 2018.
[25] M. Polmear, A.R. Bielefeldt, D. Knight, C. Swan, N.E. Canney, “Faculty perceptions of the most effective settings and approaches for educating engineering and computing students about ethics and societal impacts,” in American Society for Engineering Education Annual Conference & Exposition, Salt Lake City, UT, 2018.
[26] M. Polmear, A.R. Bielefeldt, D. Knight, C. Swan, and N. Canney. Hidden curriculum perspective on the importance of ethics and societal impacts in engineering education. American Society for Engineering Education Annual Conference and Exposition, Tampa, June 16-19, 2019.
[27] P. Gannon, R. Anderson, J.W. Spengler, and C. Plumb, “Exploring contemporary issues in sustainable energy,” in American Society for Engineering Education Annual Conference & Exposition, Seattle, June 14-17, 2015.
[28] P. Gannon, R. Anderson, C. Plumb, and D.J. Hacker, “’Frack attack: An engaging classroom activity to integrate sustainability,” Chemical Engineering Education, vol. 52, no. 4, pp. 226-231, 2018.
[29] J. W. Creswell, *Qualitative Inquiry & Research Design: Choosing Among Five Approaches*, Thousand Oaks, CA: Sage Publications, 2007.
[30] Dedoose, version 8.3.18, 2020.
[31] G. K. Kristensen and M. N. Ravn, “The voices heard and the voices silenced: recruitment processes in qualitative interview studies,” *Qualitative Research*, vol. 15, no. 6, pp. 722–737, Sep. 2015.
[32] E.A. Cech, “Culture of disengagement in engineering education?”, *Science, Technology, & Human Values*, vol. 39, no. 1, pp. 42-72, 2014.
[33] H. Zandvoort, I. VanDePoel and M. Brumsen, "Ethics in the engineering curricula: topics, trends and challenges for the future", *European Journal of Engineering Education*, vol. 25, no. 4, pp. 291-302, 2000.
[34] J. Darby, "The effects of the elective or required status of courses on student evaluations", *Journal of Vocational Education & Training*, vol. 58, no. 1, pp. 19-29, 2006.
[35] National Society of Professional Engineers. Code of ethics. Retrieved from https://www.nspe.org/sites/default/files/resources/pdfs/Ethics/CodeofEthics/NSPECodeofEthicsforEngineers.pdf, 2018
[36] National Academy of Engineering, “Overcoming challenges to infusing ethics into the development of engineers: proceedings of a workshop”, The National Academies Press, Washington DC, 2017.

Appendix: Focus Group Question Protocol

1. What is your major and year in school?
2. [If the course is an elective] Why did you choose to take this course? [If the course was required] What were you hoping to get out of the course?
3. In what ways do you think this course is helpful in building your ability to recognize ethical dilemmas?
    a. Did you feel like you could express disagreement in the class when discussing ethical issues?
    b. In what ways could the course do this better?
4. In what ways have you found this course helpful in building your ability to evaluate different options when confronted with an ethical dilemma?
5. What has been the most effective way to learn about these topics?
6. Has the course encouraged your interest in ethical issues? If so, how?
7. What questions do you still have about ethical issues that you think this course could be more helpful in addressing?
8. Do you have any suggestions for how you might more effectively learn about ethical issues in this class?
9. What is the role of the engineering profession in ethical issues?
    a. Are there any ethical issues that you think engineers should be involved in? If so, how?
10. How does ethics fit in with other topics you are learning in engineering?
    a. Are there other classes or activities in which you have learned about ethics?