“Our Little World”: (Un)envisioning the Social and Ethical Implications of Engineering

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***Abstract*—This Research Full Paper explores how undergraduate students understood the social relevance of their engineering course content knowledge and drew (or failed to draw) larger social and ethical implications from that knowledge. Based on a qualitative case study conducted in a junior level engineering class, we found that the majority of students had difficulty perceiving the social and ethical aspects of engineering as important or appropriate topics in an engineering course. Many students only considered the immediate technical usability of or improved efficiency from technical innovations as the primary social and ethical implications of engineering. This study investigates a potentially critical flaw in the structure of engineering programs, highlighting the limitations that accompany a discipline-specific academic focus. Highly structured programs leave little room for engineering students to interact with other students/programs on campus, and limit opportunities to engage in meaningful interdisciplinary discourses and expand their perspective.**

Keywords—engineering ethics, undergraduate engineering students, cultural analysis, qualitative case study

I. INTRODUCTION

This paper explores how undergraduate students understood the social relevance of their engineering course content knowledge and drew (or failed to draw) larger social and ethical implications from that knowledge. We examined what value students placed on the potential social or humanitarian impact of engineering and how they viewed the role of engineers in society and engineering ethics.

II. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

During the past two decades, the ethical dimension of engineering work, as well as engineers’ social and ethical awareness, have emerged as important issues for scholarly discussions, and gained growing attention from both the public and professional engineering communities. Engineers are considered effective problem solvers, but tend to be less inclined to consider the wider significance of their work and its potential consequences [1]. However, in recent years there has been an increasing emphasis on the need for engineers to develop greater awareness of the ethical and social responsibility that their work entails [2].

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Discussion of ethics in engineering has largely focused on “microethics” and individual issues rather than wider issues that impact society, such as the implications of the development and use of new technologies and engineering innovation [1]. Herkert proposed three frames of reference for examining ethics in engineering—individual, professional and social—which can be further broken down into “microethics”, concerned with individuals and the internal relations of the engineering profession, and “macroethics”, referring to the collective social responsibility of the engineering profession and to societal decisions about technology. He pointed out that there have been few attempts to integrate microethical and macroethical approaches to engineering ethics. He suggested that professional engineering societies should play a more proactive role in linking individual and professional ethics, and in linking professional and social ethics.

Near the turn of the 21st century, the Accreditation Board for Engineering and Technology (ABET) implemented the following measure for their programs: Criterion 3 – Program Outcomes, which requires students to be able to design systems, components, and process within ethical guidelines [3]. The ABET Engineering Criteria 2000 (EC2000) took this assessment standard a step further by requiring engineering programs to demonstrate that their graduates have an understanding of professional and ethical responsibility (Criterion 3.f) [3]. To meet this measure, many educational institutions developed a new course or program on engineering ethics assisted by researchers utilizing various instructional and evaluation methods (e.g. case studies, introduction to engineering ethics or moral theory, simulation of engineering ethics) to evaluate engineering students’ ethical awareness and efficacy in dealing with ethical decision making [4]. How these

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programs really facilitate (and hopefully positively affect) engineering students' ethical awareness in relation to their professional work is hardly known.

Bairaktarova and Woodcock [4] presented evidence that engineering students are "ill-prepared" for the ethics portion of the Fundamental Engineering (FE) examination. The FE exam (required for gaining professional engineer licensure) is a nationally administered examination designed to test the knowledge gained from an ABET-accredited engineering program, regardless of instructional methodology or implementation of engineering ethics education [5]. Data collected from the Survey of Engineering Ethical Development (SEED) project revealed that engineering students made no gains in their knowledge of ethics on the FE examination [4].

Understanding the larger institutional context of engineering education programs in higher education is also essential to understanding the current challenges in teaching engineering ethics to undergraduate engineering students. The growing proverbial elitism in engineering education, which proudly promotes high admission/selectivity standards at (unwittingly) the expense of diversity [6], focuses heavily on "hard skills" (e.g. mathematics, coding, data analytics), and leaves little room for ethical development or the improvement of other professional skills. Hess and Fore [7] highlight this lack of interest in professional skills in their meta-analyst of engineering ethics implementation in higher education, "… commonplace in our site visits for faculty, even department chairs, to be unaware of whether or how their program supports its students' ethical-professional development (p. 332)."

III. Methods and Data Sources

Our research is a qualitative case study conducted in a junior level engineering class at a large public university in the Southeast. The university is a co-educational, urban research institution with an enrollment of approximately 28,000 students. The overall student demographics are fairly diverse, consisting of 60% Caucasian, 17% African-American, 7% Hispanic, 5% Asian/Pacific Islander, 6% other/unknown, and 5% international students. The College of Engineering has over 3,500 enrolled students, including 61 students who received GI benefits in 2017.

ENGR 3999 (a pseudonym) is an elective class available to all engineering majors. This course was designed to give both veteran and non-veteran students the opportunity to gain knowledge on military technology applications and job opportunities. ENGR 3999 focuses on theories, research, and technological applications closely related to military purposes or military contexts (i.e. jet propulsion, rockets, underwater propulsion, high-speed vehicles), and exposes students to various experimental labs which involve configuring instrumentation and data acquisition, as well as analysis of data collected during experiments. The course is taught twice a week; one day is dedicated to lecture, and the other focuses on the application of the acquired knowledge in experimental labs. The course, a relatively new one first taught in Fall 2015, has become a popular elective class among juniors and seniors, mostly mechanical engineering students.

Thirty engineering students were enrolled in the course during the Fall 2017 semester. The engineering students were all upperclassmen (i.e., juniors and seniors). The sample consisted mostly of male engineering students (n=25), of which 88% (n=22) were Caucasian, 20% (n=5) were student veterans, and 28% (n=7) were minority students of different races/ethnic backgrounds (five African-Americans, one Hispanic, and one Asian-American). The sample included five female students (four Caucasians and one African-American). The instructor, as well as the two teaching assistants who helped throughout the course, were all Caucasian males. One of the teaching assistants was a student veteran.

Data were collected from 30 students through pre and post-course surveys, class observations, student reflective journals, and focus group interviews at the end of the semester. The pre and post-surveys (featuring several learning outcome measures) and reflective journals were required course activities, although they were not graded; student participation in the focus group interview was optional. A counseling Ph. D student who had conducted class observations throughout the semester clearly explained to the entire class that participation in the focus group was totally voluntary, yet she also encouraged students to participate since the focus group interview data would be one of the most important data sets to evaluate this newly implemented course. In the end, all students participated in one of six randomly organized focus groups led by three different research team members. There was no incentive given to the students to participate in the focus groups.

The focus group interview protocol included several key questions about the students' motivation to enroll in the class, as well as their overall learning experiences during the course. One question in the protocol specifically probed the students' views of how the coursework could be relevant to important social issues or humanitarian causes. ("How do you think the knowledge and skills obtained in this class can be related or applicable to some important contemporary social issues (or some humanitarian causes)?" Students submitted four reflective writing assignments during the semester, each featuring four to six open-ended questions. Students were free to write a response of any length to each open-ended question. Typical responses ranged from a short sentence to a paragraph at most. The last reflective journal prompt had an open-ended question similar to the one asked in the focus group interview. ("Have the knowledge and skills you have learned in this course impacted/changed your view regarding the roles of engineers and engineering knowledge in larger society and for various groups of people? If so, how?"). All six focus group interviews were transcribed verbatim by a member of the research team and immediately reviewed by the interviewer to ensure accuracy. Student reflective journals were also compiled and provided to the research team for analysis.

It should be noted that the ENGR 3999 course instructor and TAs did not explicitly engage the students in any discussion of ethical issues during the semester. They designed the course contents around non-lethal technologies like parachutes, rocket and jet engines, radio communication, and research tools. Since this was a junior level class, all students had completed another introductory engineering class that covered engineering ethics and engineers' social responsibilities. For the purposes of this paper, only the reflective journal responses and focus interview data were analyzed. All data collection activities in the course, including the six focus group interviews, were approved by the university's Institutional Review Board in advance of the study.

The research team included eight researchers, each possessing a different cultural, ethnic, and professional background. The research team was led by two faculty members, an Asian-American female who served as the qualitative evaluator for the course implementation, and a Caucasian male engineering faculty member teaching the ENGR 3999 class. Six research assistants were also part of the team including one Caucasian male Ph.D. student veteran in engineering, one Black male Ph.D. student with an engineering background, one Hispanic female Ph.D. student in counseling, one Caucasian female staff member in public health sciences, one Native American female Ph.D. student in educational research, and one Asian female Ed.D. student in higher education.

Data were analyzed collaboratively by the entire research team; peer debriefing and researcher triangulation were essential to the teamwork process. The entire team was divided into two groups, one primarily responsible for collecting data from the ENGR 3999 class, and the other charged to lead data analysis. The Asian-American faculty member led both groups and mediated overall communication between the two groups. The first group included the Caucasian engineering faculty member, the Caucasian male student veteran, the Hispanic female student, and the Caucasian female staff member. The second group consisted of the Black male student with an engineering background, the Native-American female student, and the Asian female student. We wanted to draw benefits from the first groups' intimate knowledge about the ENGR 3999 class and data collection contexts while allowing the second group's outsider perspective to generate fresh insight. The three students in the second group did not have any direct contact or relationship with the ENGR 3999 course instructor, TAs, or participating students.

Each member in the second group independently read the six verbatim transcripts and reflective journals, and identified several significant points expressed in the narrative data. The group met and discussed the points identified by each member, building consensus about the focus of the analysis and establishing an initial set of open codes. NVivo, a qualitative analysis software, was used in order to ensure consistency and thoroughness in the coding process, while the initial code list was revised based on further observations and related discussions during subsequent meetings. When focus group interview data and reflective journal entries were initially analyzed by the second group, the Asian faculty member shared the preliminary findings with the first group and asked for their input and consensus. She communicated some differing perspectives from the first group to the second group and built consensus between the two groups. In the later stage of analysis, the second group went back to literature and examined how our inductively-derived categories could be linked to and reinterpreted through some theoretical concepts (micro/macro ethics) available in the existing literature. We also situated our findings in the larger institutional and program contexts as the whole team finalized the major themes described below.

IV. FINDINGS

Findings indicated that the majority of students did not consider social implications as an important or appropriate topic in this engineering course, and they felt the curriculum should continue to focus on "the technical side". Some students equated social implications to the immediate usability or financial benefits of technological innovations in a specific industrial context (e.g., creating more efficient technology to reduce the cost of production). Students acknowledged that engineering has a great societal impact, but often struggled to provide specific examples or comment on its potential social implications. Five major themes emerged from analysis of the interviews and reflective journals: (1) Disregard, misunderstanding, and frustration, (2) Pragmatic usability as social relevance of engineering, (3) Technical efficiency as social relevance of engineering, (4) Positive contribution to society and humanitarian values, and (5) Apathy and indifference: Searching for why. These themes are further explained below with supporting evidence and quotes from students.

A. *Disregard, Misunderstanding, and Frustration*

Our analysis showed that the majority of students did not consider social relevance to be an important or appropriate topic in ENGR 3999, and they felt that the course's curriculum should continue to focus on "the technical side" (Interviewer, Focus group transcript 6). Students' responses were often unable to bridge their classroom experiences with the larger societal implications of their learning, as evidenced by this student, "…there was a lot of crossover, but it wasn't in class, it wasn't necessarily like we talked about ethical applications of any of it, we just talked about technology and learned about it." (Participant 2, Focus group transcript 6)

Similarly, students struggled to make a connection between the questions asked and their coursework, and had definitions of the social or humanitarian impact that were relegated to seemingly unrelated topics:

> "Yea, I don't think that connection was made in the class between things we learned. I think it's definitely able to be made like you can definitely make a connection between like you said the home security and all that stuff. I actually personally do that with my stuff. I have cameras and sensors in my house that I set up with things which I mean you could take things as we learn learned and apply it to that. But I don't think that connection in the class is made by the teacher… (Participant 1, Focus group transcript 3)"

B. *Pragmatic Usability as Social Relevance of Engineering*

Instead of relating "social relevance of engineering" to social propositions, some students interpreted "social relevance of engineering" as either practical usability of technology or pragmatic value to build professional knowledge and professional connections. Equating social implications of engineering to the immediate technical usability was a common occurrence in student responses. Elaborating on what he believed to be a good example of the social relevance of engineering, one student stated:

> "…in some remote area in Africa, they're using drones to actually drop medical supplies because other than that, it takes like a week or something to get a donkey in there so they have drones." (Participant 5, Focus group transcript 2)

A good number of students translated "social relevance of engineering" as "career-wise usability" including knowing about potential employment opportunities.

> "The knowledge I have gained in this class has impacted my view on the role of engineers by showing me potential future job fields I could go into." (Participant 9, Reflective Journals)

> "Before this class, I never really considered a job in the military or government, but I feel like this class did a good job of explaining what kind of jobs or opportunities are available to me. And we had like the guest lecture from NAVAIR and then there was that other guy I don't remember, the recruiter, yea we had a Navy recruiter." (Participant 4, Focus group transcript 1)

Additionally, according to one student, "social relevance of engineering" could be associated with "building interpersonal relationships/connections", and these connections were believed to promote students' course application:

> "This semester we had the pleasure of meeting a GCU undergraduate student that works for NAVAIR. Hearing him speak about what he does for the company was insightful and encouraging. It helped me make the connection and have a real-world event that showed met that real students are going out in the world and applying what they've learned at GCU to at GCU to industry." (Participant 13, Reflective Journal)

C. *Technical Efficiency as Social Relevance of Engineering*

Some students referred to expected financial benefits of technological innovations in a specific industrial context (e.g., creating more efficient technology to reduce the cost of production) as the "social relevance of engineering," with one student stating:

> "It's about how you can make this process more efficient, how can we make this less expensive, how can we release funds from this place to put in this place, is it good in other places…" (Participant 3, Focus group transcript 1)

Others focused on the size and efficiency of engineering products and methods:

> "Carbon fiber is interesting that way because it helps you reduce weight and things, you can use fuel economy. I guess that's kind of socially acceptable, beneficial." (Participant 1, Focus group transcript 3).

As a collective, many student responses to this question were notably centered on the size and cost of materials, which though important to engineering, are not necessarily humanitarian or social in nature. Though students were readily able to discuss the technical aspects of the field, which is both vitally important and necessary, they struggled to derive the larger ethical concerns surrounding them. They did, however, emphasize the importance of building objects or structures that were safe for use and would do no harm to others, as evidenced by the following quote:

> "Not to design something that could hurt somebody, so being responsible for what you say it's supposed to do, so you wouldn't build a bridge that you knew was unsafe" (Participant 3, Focus group transcript 2).

Overall, many students' opinions on the social aspect of their work were centered around efficiency, financial-consciousness, and harm-reductivism, and demonstrated a lack of critical thought on humanitarianism.

D. *Positive Contribution to Society and Humanitarian Values*

Even though numerous students were keen to identify the technical efficiency and usability of engineering, fewer were able to provide explicit examples of positive contributions engineering had made to society or comment on humanitarian values as a key component of the "social relevance of engineering". The students that offered examples of the latter tended to focus on responses within the realm of "microethics", or ethical decision-making from the individual's perspective:

> "That's in a lot of aspects the most nerve wrecking part of it, is if you're responsible for designing something that could potentially hurt somebody, be sure that it's not gonna happen because if it does, what could happen. You just wanna be sure that you've done everything you can to stop that from happening." (Participant 1, Focus group transcript 2)

Regarding "macroethics", even fewer students were able to acknowledge the importance of ethical decision-making from a large-scale institutional standpoint:

> "…a lot of the things the military deals with is kind of humanitarian, so I guess if you could develop technology that prevents war, that is the ultimate humanitarian effort, other than that, I'm not really sure, I mean yea, like, so if you can prevent stuff through technology that would be the ultimate way to help in that aspect." (Participant 5, Transcript 2)

Heckert [1] emphasizes that though much attention has been given to the teaching of ethical awareness in engineering programs from a "microethics" framework, much work remains to be done in "macroethics". Bridging the gap between the integrated approach of addressing "microethics" and "macroethics" is paramount to fulfilling ABET Engineering Criteria 2000 (Criterion 3.f): having a working understanding of professional and ethical responsibility.

E. *Apathy and Indifference: Searching for Why*

Though several students were able to provide an answer on the humanitarian aspect of engineering, others felt that the class did not shape their views on the subject, with one student stating: "No, it has not really changed my views of what an engineer is." (Participant 14, Reflective Journals). Some felt the coursework was solely tech-focused and did not include content on social concerns. A student recollected: “We definitely talked about other applications. Less like their humanitarian impacts.” She noted that:

“There was a lot of crossover, but in class it wasn’t necessarily like…we talked about ethical implications of any of it. We just talked about the technology and learned about it.” – Participant 2, Focus group transcript 6)

Another student also verified the lack of connection saying: “I don’t think that connection was made in the class between things we learned.” (Participant 1, Focus group transcript 3)

Some students’ answers offered further insight into this lack of perspective change and understanding among students, with one student stating that: “I think the answer to that question is ‘no’. Just no, I mean we learned about technology no like humanitarian impacts, it wasn’t a social studies course, it was a really specific technology course.” (P3, Focus group transcript 6)

Though some students expressed a basic understanding of engineering ethics, in general most felt that their knowledge of the issue remained unchanged and that the topic was less important compared to other aspects of their education. This study focused on the experiences of students in a single engineering course, but the lack of ethics education seemed to be endemic to the major, with one student stating:

> “I feel like as engineers, we don’t really think about that in our classes. We’re always so focused on the engineering aspect of it. You don’t really expand on ‘how is this gonna help society’ or ‘how does this tie into other areas of the world outside our little world.” (Participant 1, Focus group transcript 6).

Acknowledging the dearth of their exposure to engineering ethics and implications in larger social contexts, one participant mentioned that her peers had been somewhat insulated from the rest of students/programs on campus, which made it difficult for them to “mesh” with those outside of engineering, possibly due to the program’s heavy focus on technical work and the particular style of thinking prevalent in engineering.

> “Maybe outside of this class somewhere in the program we could have something that does show us how engineers fit into society, because sometimes the thought process on this side of campus is we’re in our own little world, and that’s the other side of campus. We don’t really feel like it’s inclusive, and I think it goes both ways sometimes, we don’t want to be inclusive. And I think sometimes we don’t feel like we can mesh with people that are outside of our little world because of the way that we think. So I don’t know if that’s something that, somewhere down the line somebody’s going to have to try to integrate a little bit better. But there is a bit of a disconnect there (Participant 1, Focus group transcript 6).”

This student, like many of her peers, recognizes a separation of engineering from other disciplines could have potentially detrimental effects. Though engineering education is a technical field, there remains room within it for curriculum that is inclusive and ethics-focused. Increasing this knowledge in students will improve the field of engineering education by making it more thorough and comprehensive, and encourage greater diversity through interdisciplinary coursework.

V. DISCUSSION AND CONCLUSION

As technology has emerged as a powerful force in leading society forward into an unknown future, it is imperative that we revisit the social and ethical responsibilities of those who work on the frontline of technological and engineering innovation. This study highlights a critical missing piece in current engineering education—the dearth of exposure and opportunities for students to engage in meaningful discussion about engineering ethics and social responsibilities throughout their coursework and program.

Findings from our study highlight major discrepancies in the moral judgment of engineering students’ micro and macro ethical reasoning. The majority of student responses tended to echo Heckert’s [1] frame of engineering ethics from the individual perspective, or “microethics”, and lacked the perspective of collective social responsibility from a large-scale institutional standpoint, or “macroethics”. A number of authors have emphasized that teaching ethics in engineering education must adequately address both micro and macro ethical domains in order to give students a working understanding of professional and ethical responsibility, and assure this knowledge leads to long lasting effects [1] [4]. This signifies a call for a renewed perspective on teaching ethics in engineering education, one that proactively examines the pedagogies of ethical awareness from both a micro and macro framework.

Scholars have acknowledged the dearth of evidence-based programmic solutions that facilitate engineering students’ ethical reasoning [4]. One possibly promising approach to improving implementation and measuring (over time) the efficacy of micro and macro engineering ethics teaching is to utilize non-traditional classroom methods. One such method is the Simulator for Engineering Ethics Education (SEEE) 1.0. SEEE 1.0 is an interactive Microsoft Windows based software designed to develop a student’s ability to identify, analyze, and respond to engineering ethics scenarios outside of the classroom environment (scenarios can be micro or macro in framework) [3]. Chung and Alfred [3] report a 32% improvement in teaching effectiveness of SEEE 1.0 over conventional non-interactive web-based resources for engineering ethics education.

Another important issue was raised by one of the student participants in our study who recounted that engineering students were “in our[their] own little world.” It is undeniable that one’s ethical development, especially expounding macroethics, is a very complex and dialogical process; there is no quick solution to facilitate that capacity. Pondering upon multiple facets of an ethical dilemma, engaging in deeper and more critical thinking, and finally expanding one’s ethical horizon inevitably requires constant exposure to several different, challenging points of view. Therefore, if we want students to expand the scope of their ethical reasoning, it seems necessary to expose them to different perspectives beyond their own disciplines. This is not an entirely new idea in higher education or in engineering education [9]; many sectors of engineering have long acknowledged the value of interdisciplinary communication and collaboration in generating new ideas and ground-breaking innovations that address the most complex problems in society. Interdisciplinary engagement may be a promising avenue in facilitating engineering students' ethical reasoning, especially with regards to meaningful development in engineering macroethics.

Despite our careful planning and coordinated effort to draw valid and meaningful interpretations from the given data set, this study presents several important limitations. Five major themes reported in this paper were drawn from a thorough textual analysis that utilized both data and researcher triangulation, ensuring their stability and trustworthiness. However, there are limitations to the extent that our findings and conclusions can be generalized. First, the research instruments used for data collection were not designed to control for unintended participant biases, such as group peer pressure or social, cultural, or institutional norms, which may have influenced student responses. ENGR 3999 is a special topics elective course, not required for degree completion by all enrolled engineering students; as such, generalizability to the engineering student population is limited. Lastly, the study's sample included 30 undergraduate students in a single case study at an ABET accredited engineering program in the Southeast. ABET indicates that as of 2016, there were 2,550 accredited engineering programs at 528 institutions of higher education throughout the United States [8]. The sample size used in this study is not representative of all engineering students or programs throughout the nation.

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