Work in Progress: Undergraduate Student Perceptions of Macroethical Issues in Aerospace Engineering

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Abstract

This work-in-progress study explores student perceptions of ethics in undergraduate aerospace engineering. Macroethics education is a topic that has been traditionally left out of aerospace engineering undergraduate programs, often leaving students ill-equipped to assess and address the positive and negative impacts of their future career field on humanity. Defined as the teaching of collective social responsibility within the engineering profession and societal decisions about technology, macroethics helps novice engineers better understand the real implications of their work in society (Hekert, 2005). Aerospace engineering has been historically dominated by white cis-gendered male students, and the privilege that this majority holds affects the lens through which students perceive macroethical concepts in the field. Thus, there is a vital need for macroethical concepts to be included in undergraduate aerospace engineering curricula.

This study extends previous iterations of our research, in which one-day macroethics lessons were implemented into undergraduate aerospace engineering courses (Benham et al., 2021). These data were used to inform the development of a survey that was distributed to students in a senior-level aerospace engineering course at a different large, historically white, research-intensive, public university (Benham et al., 2022, Ennis et al. 2023). This work seeks to investigate undergraduate students' perceptions and awareness of macroethical issues in aerospace engineering from a purely qualitative lens using a grounded theory methodological framework. Qualitative data from the survey explored students' perspectives of what it means to be an ethical engineer, unethical practices in engineering, and other related questions and were inductively analyzed to identify common themes. Preliminary findings from the data analysis–the initial coding phase of a longer constructivist grounded theory analysis–identified that students demonstrate varied levels of awareness regarding macroethics in aerospace. Students expressed levels of *acceptance,* claiming to see "both sides" of the ethical arguments and that the role of aerospace in the defense industry is a "necessary evil", or displayed *resistance,* desiring changes be made to the industry and more accountability as a consequence for their actions. In addition, students had a diverse understanding of who ultimately benefits from the aerospace industry, with students focusing on specific stakeholders, nations, or society at large. Other emergent themes explored students' understanding of the role of government/economy in the aerospace industry, ethics in professional practice, and students' feelings of conflict or apathy about the role of aerospace engineering in the defense industry. These initial themes will be used to develop broader theories about how students construct meaning around macroethics in engineering disciplines. The overarching theories will be used to inform teaching practices concerning ethics in engineering education, refine future iterations of the macroethics lesson, and increase motivation to integrate macroethical education into existing aerospace engineering curricula.

Introduction

The field of aerospace engineering has both positive and negative impacts upon society; however, current educational practices within the discipline often leave students feeling unprepared to address these ethical impacts. Moreover, these educational practices can lead students to feel that socio-political issues are tangential to their work as engineers, but in reality no career field is exempt from its social influence and responsibility (Benham et al., 2021; Cech, 2013).

Ethics education is a core requirement of ABET accreditation, which states that engineering program graduates should be able 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" (ABET, 2021, p.5). Previous research has identified that engineering ethics can be subdivided into *microethics,* which focuses on an engineer's individual

decision-making and the profession's internal relationship, and *macroethics,* which refers to the "collective social responsibility within the engineering profession and societal decisions about technology" (Herkert, 2005; Bielefeldt et al., 2017).

Macroethics education has been historically absent from undergraduate engineering curricula, and without this education, students are often left ill-prepared to think critically about ethical issues (Colby & Sullivan, 2008; Polmear et al., 2019; Benham et al. 2021; Palmer & Tawney, 2022). Students also struggle to productively engage with one another about ethical dilemmas without structured education in ethics, which is critical for understanding multiple perspectives and co-constructing knowledge about a topic. In addition, aerospace engineering is a field that has traditionally been dominated by white, cis-gendered, male students, and the privilege that this majority holds ultimately affects how students perceive relevant macroethical issues (Orr et al., 2015). Therefore, macroethics education could also be a tool that helps reshape engineering education from its original logical positivist perspectives to those rooted in justice. In this study, the authors explore the following research question:

What are students' perceptions and awareness of macroethical issues in aerospace engineering?

These questions were developed through three cycles of implementing one-day macroethics lessons into undergraduate aerospace engineering courses, using student feedback to inform and guide future lesson iterations, and analysis of student perceptions about macroethics in their program but also the aerospace industry (Benham et al. 2022).

Previous research has explored how to include socio-technical and ethical content in existing engineering courses through activities that use stakeholder mapping or role-playing with "structured controversies" to push students to consider different people or groups affected by technological advancements (Andrade & Tomblin, 2018; Wareham et al. 2006; Gupta, 2017). However, these works do not address students' perceptions of their learning. Our research team seeks to understand these student perspectives, as they will be used to shape future iterations of the macroethics lessons. Other researchers have attempted to update existing engineering courses to include more ethics content, activities, and instruments to address student awareness, but these are often applied within graduate level courses, where understandings of their engineering disciplines are much more advanced (Jimerson et al. 2013, Palmer & Tawney, 2022, Davis et al., 2022). We seek to understand how similar interventions within a one-day macroethics-focused lesson could potentially impact an undergraduate population; but more importantly, we want to explore undergraduate engineers' perceptions about macroethics within the aerospace discipline.

Methods

Within this work-in-progress study, we report on data from the administration of the most recent iteration of our macroethics survey to undergraduate engineering students (n = 69). In this iteration, the survey was implemented within a senior-level space systems design course at a large, Midwestern, historically white, research-intensive, public university. The course serves as an introduction to the engineering design process for space systems, including technical content such as mission planning, launch vehicle integration, or propulsion. In addition, ethical content related to the technical material, such as space territorialization, climate change, and nuclear propulsion, were incorporated into the lesson plans throughout the semester. This particular course was chosen as the sample for our study due to several members of our research team making up the class instructional team.

The survey instrument was designed to capture students' perceptions of macroethical topics in aerospace engineering. It was delivered in Qualtrics, and includes Likert-scale questions asking students to identify to what degree they agree or disagree with statements about ethics in aerospace engineering and if and how they have experienced macroethics in their own undergraduate education (see Appendix A). It also

has questions regarding identity-based mistreatment in aerospace engineering and open-ended questions inquiring about diversity within aerospace, companies they believe to be engaging in unethical practices, the role of aerospace within the military-industrial complex, and possible effects of satellite megaconstellations. The open-ended survey responses are the focus of this study, as previous iterations of our work have detailed quantitative findings from another undergraduate student population (Benham et al., 2022).

The data analysis was led by the first author, who is not a part of the course instructional team. The second and fourth authors are the graduate teaching assistant and faculty instructor of this course, respectively. During the data analysis phase of the study, the first author organized qualitative survey data to be inductively coded, specifically pulling out student responses for the following survey questions:

- *What are aerospace companies' practices that you consider to be unethical?*
- *What does it mean to be an ethical aerospace engineer?*
- *How do you feel about the fact that so much of the aerospace industry is involved in national defense?*

We use constructivist grounded theory as a methodological framework to guide our comprehension of student response data in this and future related works. Constructivist grounded theory is a process that allows researchers to generate theory through inductive analysis of qualitative data rather than utilize existing theoretical frameworks (Charmaz, 2006; Chun Tie et al., 2019). We use this approach in order to understand how undergraduate aerospace engineers construct meaning around the concept of macroethics and are working to develop a comprehensive theory that addresses our research questions. The data analysis for this work-in-progress represents the initial and intermediate coding phases of the constructivist grounded theoretical process, which is described in detail below.

Responses for each of the open-ended questions were read through and inductively coded by the first and second authors. During the initial coding stage, both researchers separately went through the qualitative data and identified important words or ideas present, while documenting initial thoughts, rationale, or questions in the form of short memos. After an introductory pass through the responses, the researchers met together to review their initial codes, discuss similarities and differences across student responses, and ask clarifying questions about their interpretations of the responses. The researchers then developed a shared list of focused codes to encapsulate their analyses of student responses and began defining their initial codebook. Future iterations of data analysis will refine our initial themes through the use of theoretical sampling (Chun Tie, 2019). Once we have established relationships between core conceptual categories, a final advanced coding phase will take place in order to synthesize an overarching theory to explain findings from student data.

Preliminary Results and Future Work

Within participant data, we identified themes about student awareness of macroethical dilemmas and varying interpretations of who ultimately benefits from the aerospace industry. These themes and their corresponding subcategories are detailed in the following sections. In addition, initial themes regarding the role of the government and economy in the industry, ethics in professional practice, and students' feeling of conflict and/or apathy regarding the industry's role in national defense also emerged from student response data.

Awareness of Macroethics in Aerospace Engineering

Based on the initial coding phase of survey data, several themes relate to students' understanding of macroethics in aerospace have begun to emerge. Themes categorized as *acceptance,* in which students recognize unethical aspects of the aerospace industry but are uninterested in changing current practices,

and *resistance,* in which students recognize unethical implications of aerospace and express a desire to disrupt the system and reform the field, are both described in Table 1.

Table 1. Initial Themes Relating to Student Awareness of Macroethics in Aerospace Engineering

Theme	Definition	Example Excerpt
Sees Both Sides **(Acceptance)**	Students feel that there are valid arguments on "either side" of ethical dilemmas within the field.	"I believe it is a poor reflection on the community but is also important to understand that military spending has been fundamental to finding new advances that help the world outside of the military's direct influence"
Necessary Evil **(Acceptance)**	Students are aware that the effects of the aerospace industry can be negative for some, but overall it is necessary.	"The US has become a superpower that cannot ignore the evils of this world. Even though some work may be ugly, it's necessary. The world isn't unicorns and rainbows."
Accountability **(Resistance)**	Students want the aerospace industry to accept responsibility for their actions	"...we must hold accountability to the people in our industry that also try to become the evil we are so desperately trying to defend against"
Desire to Change Industry **(Resistance)**	Active or passive hopes that the aerospace industry will change	"I wish there was more emphasis on research and development that will help people in innovative ways"

The idea that there are fair claims on both "sides" of ethical dilemmas presents a significant challenge regarding students' ethical understanding, as it assumes that 1.) there are only two sides to a macroethical problem and 2.) both contain equally valid reasoning. Wherein reality, clear and systemic power imbalances are often at the core of these issues. In addition, students recognizing the role of the aerospace industry within the military-industrial complex as a "necessary evil" has potentially negative implications for the development of ethical engineers. This is because it inherently assumes that the negative effects of the industry can be condoned in pursuit of positive effects that are often abstract at best. It is difficult to assert that the ends of the defense industry justify the means; given that it means prioritizing innovation, capital, and national defense over the exploitation of marginalized populations, finite resources, and non-defense sectors of the aerospace workforce. Students seeing both sides and necessary evils in aerospace macroethics are both concerning findings, as they suggest that future engineers are willing to accept the current implications of aerospace engineering in the defense industry and continue to uphold the problematic and hegemonic nature of the discipline. These student perspectives are an important first step towards improving macroethical education in engineering, as instructors must first address these problematic dispositions before engaging students further in ethics.

In our future work, we will further explore these themes of acceptance and resistance regarding the current state of macroethical dilemmas in aerospace engineering, as well as how students actively or passively desire to disrupt the current system. We define 'passive' in this sense as a generic wish that the system changes, whereas 'active' involves wanting to play a specific role in the improvement of the

aerospace industry. We would also like to learn how students' background and previous experiences play a role in the development of these perceptions.

Stakeholders Who Benefit from Aerospace Innovation

Themes regarding who students felt were ultimately affected by the industry also emerged from the data. Stakeholders, in this context defined as parties that are impacted by the aerospace industry, such as *specific groups*, *the commercial aerospace industry, the United States, society*, and *the world* all were identified with participant data and are detailed in Table 2.

Table 2. Introductory Themes Regarding Student Perceptions of the Identification of Aerospace Stakeholders

Theme	Description	Example Excerpt
Specific Groups	Distinct individuals such as peers, communities, or a population majority that benefit, implying that there may be other groups that will be harmed.	"Being an ethical aerospace engineer means to do what is right for the sake of the community, without infringing on basic human rights."
Commercial Aerospace Industry	Innovation from aerospace in the defense industry ultimately helps the commercial industry as well.	"I think a lot of innovation begins in defense work and trickles down to commercial work."
United States of America	Developments within the aerospace industry support and sustain the American way of life, even if it conflicts with desires of other nations.	"An ethical aerospace engineer will continue creating technologies that will enable the United States to maintain control over other worse bad actors."
Society	Innovation within the aerospace industry should be able to benefit society at large.	"The money that is initially invested in defense in the aerospace industry eventually trickles into the public domain benefitting society as a whole (like GPS)."
World	More than just humanity benefits from the aerospace industry. In this case, the entire planet is taken into consideration.	"I believe that it means thinking about the consequences of every step taken or decision made, both to the environment and to human beings."

Given that macroethics focuses on the larger societal implications of a discipline such as aerospace engineering, we would like to further analyze how students' develop understandings of stakeholders in the industry. In addition, we want these initial findings to inform how our macroethics lessons address the various scales of stakeholders within the aerospace industry. We hope to use these lessons to broaden

students' understanding of who is affected by aerospace technology beyond immediate stakeholders such as government bodies or aerospace companies.

Conclusion

This initial analysis of qualitative survey data demonstrates that undergraduate aerospace engineering students have a wide range of perceptions about macroethical issues in the field, specifically how students reconcile the aerospace industry's involvement in the defense industry by "seeing both sides" and deem it a "necessary evil" or oppose the system in place and desire accountability and change. Students also shared a variety of perspectives about who they feel the aerospace industry is meant to benefit, where ethical practices may or may not be present within the aerospace industry, and how the government and economy contribute to the role of aerospace engineering in systems such as the military-industrial complex.

Based on these preliminary findings, we plan to continue using a constructivist grounded methodological process to refine the preliminary themes that emerged from participant data in future work. We intend to assess our findings through theoretical and purposeful sampling and then use our themes to synthesize theories about how macroethical understandings are formed by undergraduate engineering students. These initial findings have significant implications about how engineering students have constructed their knowledge about ethics to date, but also work to inform teaching practices of educators who are willing to address how students should be learning about engineering macroethics and improve the perceived gap in student understanding. In addition, our findings and corresponding theories will be used to further develop our one-day macroethics lessons, as we hope to broaden students' understandings of who could be impacted by the aerospace industry. For instance, now that we have a working knowledge about students' perspectives about macroethics, we can tailor our readings and activities to highlight lesser-known viewpoints about aerospace-specific ethical dilemmas. This can prompt further growth in these students' understanding of these issues and better prepare them to address the ethical implications of aerospace once they are practicing engineers.

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Appendix

A. Qualtrics Survey Instrument Questions

1. Please indicate how much you agree with the following statements (*Likert-scale from strongly disagree to strongly agree*)
    a. Aerospace engineering is a "technical" space where "social" or "political" issues such as inequality are irrelevant to engineers' work.
    b. It is easy to be an ethical engineer in the aerospace industry.
    c. Ethical issues do not pertain to new aerospace technologies or systems.
    d. Technology can't be good or bad in itself. What matters is how people choose to use the technology.
    e. I know of aerospace companies that I wouldn't consider working for because their practices are unethical.

    i. What are the aerospace companies' practices that you consider to be unethical?

2. Please indicate how much you agree with the following statements (*Likert-scale from strongly disagree to strongly agree*)
    a. In my engineering coursework thus far there has been a substantial emphasis on macroethics in aerospace engineering.
    b. As a whole, my professors have avoided discussions of macroethical issues.
    c. In my classes, I have often had the opportunity to initiate discussions regarding macroethical issues.
    d. Undergraduate engineering students are able to learn about macroethics.
    e. My professors have rarely expressed personal concern over macroethical issues in aerospace engineering.
    f. I wish there was more emphasis on macroethics in aerospace engineering in my engineering coursework.
    g. The ethical curriculum I have received so far has prepared me to engage in respectful and challenging dialogue with my peers.
    h. I feel prepared to consider macroethical issues in the aerospace industry today.
    i. My aerospace professors have the knowledge necessary to teach me about macroethics in our classes.

3. I am personally concerned about being treated differently in aerospace engineering spaces because of some aspect of my identity (Please check all that apply):
    a. Race/Ethnicity
    b. National Origin
    c. Gender Identity / Expression
    d. Sexual Orientation
    e. Disability Status
    f. Veteran Status
    g. Age
    h. Religion/Creed
    i. Other (Please specify below)
    j. None of the above

4. What aspects of people's identities do you believe are marginalized within aerospace engineering spaces? (Please check all that apply):
    a. Race/Ethnicity
    b. National Origin
    c. Gender Identity / Expression
    d. Sexual Orientation
    e. Disability Status
    f. Veteran Status
    g. Age
    h. Religion/Creed
    i. Other (Please specify below)
    j. None of the above

5. In what courses at Michigan have you learned about macroethics in engineering? (Open-Ended)

6. What does diversity in aerospace engineering mean to you? (Open-Ended)

7. Satellite megaconstellations are systems that provide satellite internet through a group of orbiting satellites. SpaceX has currently launched 1,800 of their planned 4,000+ Starlink satellites, and

Amazon is developing their own megaconstellation, called Project Kuiper, with 3,000+ satellites. Have you heard of satellite megaconstellations before? (Multiple-Choice)

8. Name potential effects of a satellite megaconstellation and indicate whether you feel each effect is positive or negative for society. (Up to 3) (Open-Ended)

9. The major U.S. aerospace companies make most of their revenue on defense-related systems. (For example, Lockheed Martin's revenue is 96% defense, and Boeing's is 56% defense. See https://people.defensenews.com/top-100/ for more information).
    a. How do you feel about the fact that so much of the aerospace industry is involved in national defense?

10. What does it mean to be an ethical aerospace engineer?