Board 240: Developing Critically Conscious Aerospace Engineers through Macroethics Curricula: Year 1

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Introduction

Absent from the undergraduate aerospace curricula at many universities is any acknowledgement of macroethics, the ways in which engineering impacts society positively and negatively [1]. For example, aviation makes the world a smaller place, but aircraft emissions also contribute to climate change [2], [3]. Satellite internet megaconstallations provide internet access to places that were previously unconnected, but also contribute to light pollution that negatively impacts astronomy [4]–[6]. And, many career pathways in the aerospace industry relate to military and weapons technology design, development, operations or maintenance, resulting in significant macroethical dilemmas regarding the interconnections between engineering and violence [7], [8].

Without putting aerospace engineering in its social context, students are left ill-prepared to recognize and address challenging ethical questions and issues they will encounter in their future engineering careers. Alternatively, aerospace engineering curricula should support the development of the critical consciousness (see [9]) required to reflect on the social impact of the field and students' present and future roles within it. We are addressing this pressing need with integrated curriculum development research initiatives. Our multi-institutional team is composed of aerospace and engineering education research faculty, graduate students in engineering education, undergraduate students in engineering, and practitioners in the aerospace industry. This paper highlights the results thus far and describes the ongoing work of the project, one year into NSF IUSE grants DUE-2236148 and DUE-2236227.

Curricular Development

The overarching objective of our design-based research project is to investigate how a macroethical curriculum can be effectively integrated into aerospace engineering science courses. In the Fall of 2023, we implemented macroethics lessons in a sophomore-level introduction to aerospace course and a junior-level spacecraft mechanics course at the University of Michigan (U-M). In the Spring of 2024, we implemented macroethics lessons into a senior-level space systems design course at U-M, a sophomore-level introduction to aerospace course at the University of Colorado Boulder (CU Boulder), and a senior-level propulsion course at California State University, Los Angeles (Cal State LA).

The macroethics lesson in the Fall 2023 spacecraft mechanics course focused on space debris and was a revision of a lesson offered the previous year in the same course. The first author of this paper facilitated this lesson, which introduced students to the concepts of positionality and ethical lenses and then engaged students in a dialogue about how different ethical lenses would approach the issue of space debris. The lesson was received well by students who attended class and completed a post-lesson survey (Figure 1). In the Fall of 2024, a consultant on the project,

who is an assistant professor in the Herbst Program for Engineering, Ethics & Society at CU Boulder, reviewed this lesson material and a recording of the first author's facilitation to provide feedback.

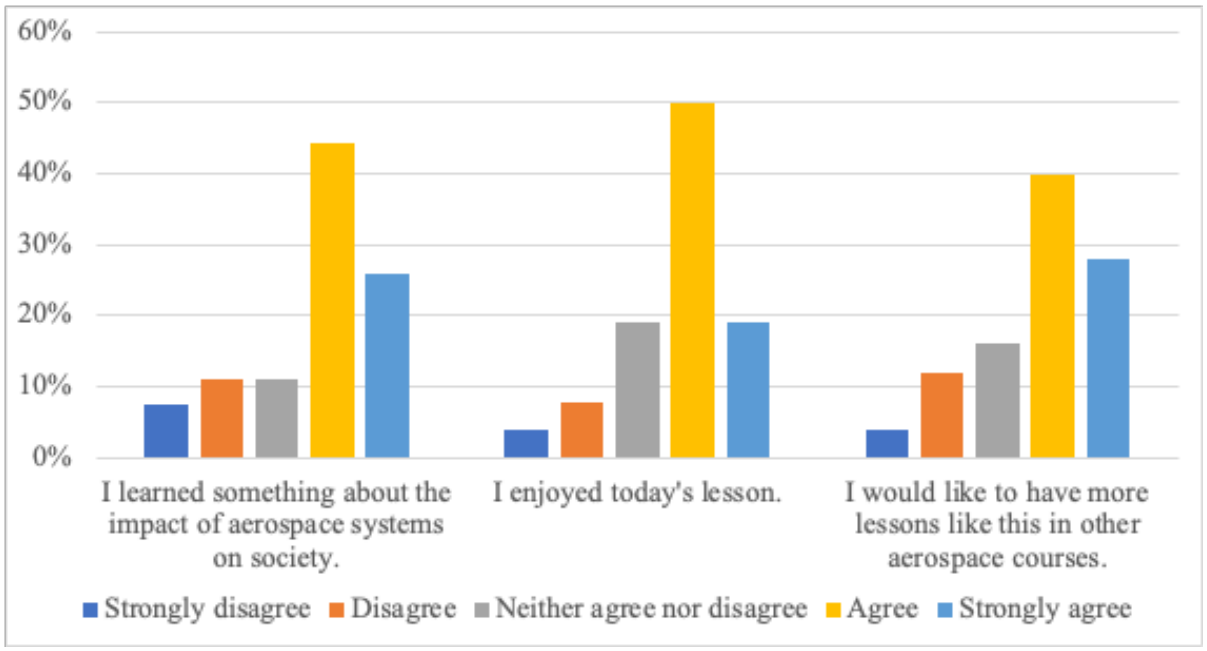

Figure 1. Student response to the macroethics lesson in spacecraft mechanics (n = 27 of 40 enrolled)

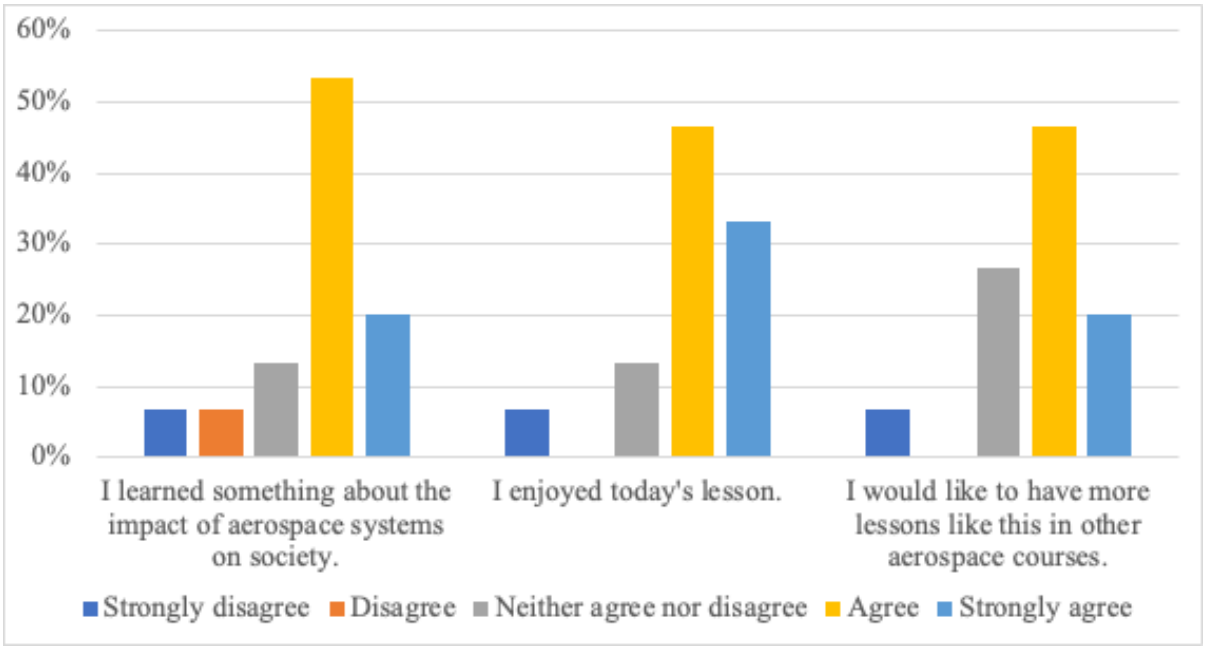

Figure 2. Student response to the macroethics lesson on drones in introduction to aerospace (n = 15 of 143 enrolled)

There were two lessons in the Fall 2023 introduction to aerospace course at U-M, which was also taught by the first author of this paper. We designed and implemented two 50-minute lessons, one on the use of drones for humanitarian purposes and one on spaceports (i.e., rocket launch facilities). In the first lesson on drones, students read articles about Zipline, an autonomous logistics company that got its start delivering blood in Rwanda in 2016, and then discussed what they thought Zipline had done well, what concerns or criticisms they had of the company, and who they thought benefitted from the existence of the company's system. In the second lesson on spaceports, students learned about common technical requirements of spaceports–that they be on the equator, that they have water to the east, and that they be far from major population centers. Then, students discussed where they would site a spaceport in southeast Michigan and made a map showing the relative power and impact of rights-holders who would be affected by such a spaceport. We have since repeated this spaceports-themed activity in multiple venues at U-M: in the first author's space systems design course, a lunchtime macroethics dialogue series, and a community dialogue facilitated for the Industrial & Operations Engineering Department.

We did not survey students about their opinion of the spaceports lesson. The drone lesson was received well by students who attended and completed a post-lesson survey (Figure 2), although we noted several necessary improvements. As could have been expected, providing students with positive-leaning articles from a single perspective about a specific company [10], [11] centered the discussion on this company and its successes, rather than on critical discussion of macroethical issues. We had a similar experience in Spring 2023, when we facilitated two macroethics lessons at CU Boulder. We used articles to seed the discussion, but this narrowed the discussion more than we would have liked. For example, we provided an article about the use of US weapons in Yemen for our discussion about the military-industrial complex [12]. But,this narrowed the conversation to this specific conflict, whereas we intended for students to discuss the military-industrial complex as a whole. Furthermore, using news articles to frame discussion does not allow for critical discussion on the debatable motivations of for-profit companies doing humanitarian work within systems of capitalism. For these reasons, we decided to write issue briefs [13] to provide information for the Spring 2024 discussions, which focused on the military-industrial complex (at CU Boulder and Cal State LA) and the environmental impacts of spaceflight (at CU Boulder). These issue briefs offer concrete, factual information related to the topic to be discussed as well as present multiple perspectives on the macroethical impact of the work, including perspectives of marginalized populations and communities not forwarded in mainstream discourse. We have now developed and utilized several issue briefs and are currently developing more on additional topics.

Research

In the research arm of this project, we ask two research questions to understand students' perceptions and inform the development of curriculum:

> RQ1) What are undergraduate students' current awareness and perceptions of macroethical issues in aerospace engineering?
>
> RQ2) In what ways do students feel their education is or is not preparing them to address macroethical issues?

We also pose a question to assess our curriculum:

> RQ3) How does the macroethical curriculum impact students' perceptions and awareness of macroethical issues and their desire to engage with the macroethical implications of their future work?

In the first year of our project, we are developing a survey to conduct quantitative and qualitative analyses of students' awareness and perception of macroethical issues in aerospace engineering, as well as their educational experiences on the topic. A pilot study of a proposed two-factor structure based on RQ1 and RQ2 did not offer evidence of validity via confirmatory factor analysis (see the poor fit shown in Figure 3) [14], [15]. However, exploratory factor analysis (see Table 1) resulted in five factors that serve as sub-themes [15]:

1. The criticality of the relationship between aerospace engineering and society
2. The ease or difficulty of being an ethical aerospace engineer
3. Technical determinism and aerospace career pathways
4. Macroethics discussions within aerospace coursework
5. The ability of faculty to facilitate conversations on the macroethics of aerospace

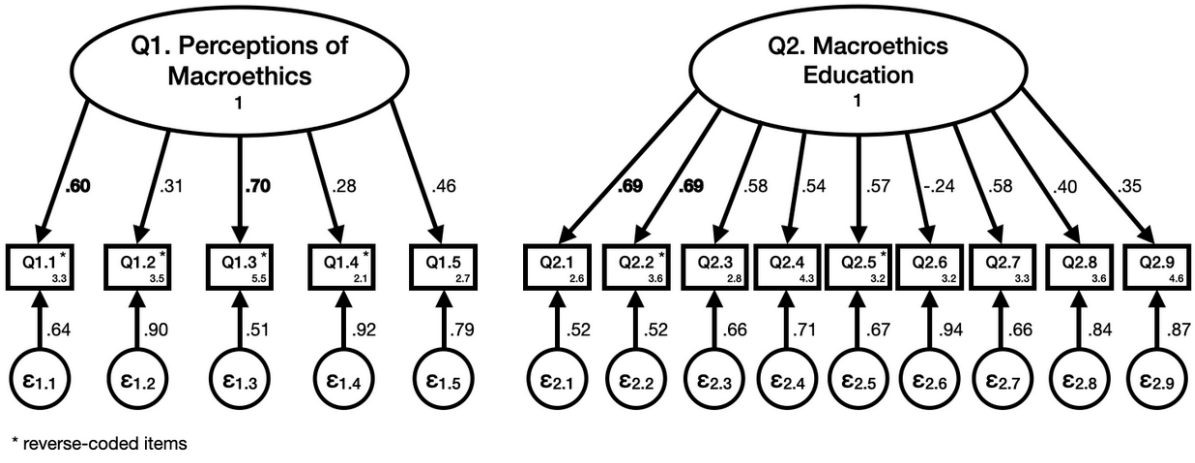

Figure 3. Results of confirmatory factor analysis of survey responses

These sub-themes have aided in the development of additional survey items. The current version of the survey features 28 Likert-scale questions about students' perceptions of the current state of aerospace engineering and their experiences in an aerospace engineering program and 13 Likert-scale questions about their idealized vision for the aerospace engineering field and what they would like to see in their aerospace engineering program. Of these 41 questions, 8 are followed with open-ended questions that ask students to explain their answers in more detail.

Table 1: Results of exploratory factor analysis of survey responses

Item	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Q1.1 *		**0.725**		0.101	
Q1.2 *					**0.715**
Q1.4 *				**0.792**	
Q1.5	0.202	0.301	-0.189	**0.388**	
Q2.1	**0.767**				
Q2.3	**0.621**			-0.184	0.112
Q2.5 *	0.205	0.161	**0.595**		-0.112
Q2.6	-0.185	**0.683**	0.140		0.144
Q2.7	0.294	-0.138	**0.374**		

* reverse-coded items

Qualitative analyses of these responses have progressed our understanding of students' perceptions on macroethical dilemmas, highlighting an array of stances ranging from acceptance to resistance [16], [17] (see Table 2, [16]). The survey also concludes with 10 demographic items intended to capture students' identity, including their race, gender identity, citizenship, political beliefs, and other factors. This data allows for future exploration of the relationship between identity and students' perceptions of macroethics and macroethical education. Future research

Table 2. 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"

must also investigate RQ3, as we are currently still developing curriculum for the macroethics lessons.

Conclusion

One year into the grant, this project is working to center the impacts of aerospace engineering on both society and the environment, and to engage students in critical reflection to analyze and understand the implications of their present and future work. We do so in a manner that forwards marginalized perspectives often absent from mainstream discourse. Ongoing research explores students' current perceptions of the field, supporting the development of curricula that are challenging and impactful. This work offers opportunities for students to develop critical consciousness and realize the impact they can make on their own communities through a career in aerospace engineering.

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