Work in Progress: Implementing an Orbital Debris Macroethics Lesson in a Junior-Level Spacecraft Dynamics Course

Megan Ennis, University of Michigan

Megan Ennis is a master's student in aerospace engineering and a research assistant with the SHUTTLE Lab at the University of Michigan. After completing a B.S. in aerospace engineering at the University of Michigan, she spent a year at University of Cambridge for a master's in gender studies. She returned to Michigan and is now enjoying her time as a graduate student instructor. Beyond being involved in the lab's macroethics work, Megan's research interest is to apply feminist theories to engineering education.

Ms. Elizabeth Ann Strehl, University of Michigan

Elizabeth is a graduate student at the University of Michigan studying Engineering Education Research under doctoral advisor Aaron Johnson. Her research focuses on weaving macro ethics into existing aerospace engineering curricula and institutional support methods for working class engineering students. Elizabeth earned her undergraduate degree from the University of Michigan in 2019 with foci in Biomedical Engineering and Applied Mathematics.

Dr. Aaron W. Johnson, University of Michigan

Aaron W. Johnson is an Assistant Professor in the Aerospace Engineering Department and a Core Faculty member of the Engineering Education Research Program at the University of Michigan. He believes in a strong connection between engineering education research and practice, and his research leverages his experience teaching engineering science courses to bridge the gap between theoretical, well-defined coursework and ill-defined, sociotechnical engineering practice. Aaron holds a B.S. in Aerospace Engineering from U-M, and a Ph.D. in Aeronautics and Astronautics from the Massachusetts Institute of Technology. Prior to re-joining U-M, he was an instructor in Aerospace Engineering Sciences at the University of Colorado Boulder.

Dr. Corin L. Bowen, California State University, Los Angeles

Corin (Corey) Bowen is an Assistant Professor of Engineering Education, housed in the Department of Civil Engineering at California State University - Los Angeles. Her engineering education research focuses on structural oppression in engineering systems, organizing for equitable change, and developing an agenda of Engineering for the Common Good. She teaches structural mechanics and sociotechnical topics in engineering education and practice. Corey conferred her Ph.D. in aerospace engineering from the University of Michigan - Ann Arbor in April 2021; her thesis included both technical and educational research. She also holds an M.S.E. in aerospace engineering from the University of Michigan - Ann Arbor and a B.S.E. in civil engineering from Case Western Reserve University, both in the areas of structural engineering and solid mechanics.

Oliver Jia-Richards, University of Michigan

Oliver Jia-Richards is an Assistant Professor of Aerospace Engineering at the University of Michigan, and received his Sc.D. in Space Propulsion and Controls from the Massachusetts Institute of Technology. His research interests lie in the domain of space systems, with particular attention on the applications of electric propulsion devices and related technologies for space exploration.

Work in Progress: Implementing an Orbital Debris Macroethics Lesson in a Junior-Level Spacecraft Dynamics Course

Introduction and motivation

Aerospace engineering is not exempt from its social responsibility, as is seen through the issues of space resource mining, orbital debris pollution, the military-industrial complex, space tourism, and space territorialization. Current engineering education not only disconnects students from their social influence as practicing engineers but perpetuates injustices by denying their destructive effects within a supposedly meritocratic culture [1]. Only focusing on the technical components of an engineering role assumes that the social responsibility lies with others in their field, for example people in leadership positions or activists. However, if within aerospace engineering everyone assumes others hold the responsibility then no one believes they hold any themselves. These assumptions allow the hegemonic norm (the supposed meritocratic culture) to continue without question. There is a need for social-technical education within aerospace engineering to equip students with their own confidence to consider what they see around them and what personal responsibility and power they may hold or lack [2]–[5]. Students may become better prepared by learning about the history of aerospace engineering, the people who participate in aerospace engineering, and how aerospace engineering affects politics, resources, science, the environment, and exploration.

This work in progress paper reviews how a macroethics lesson was piloted within a junior-level spacecraft dynamics course in the undergraduate aerospace engineering program at the University of Michigan. The lesson introduced students to one macroethics topic, orbital debris, that directly connects to the "technical" topics of the course. We believe this socio-technical integration stressed to students that engineering cannot be separated from its societal impact. This paper reviews previous macroethics work, context about the course, the content and structure of the lesson, a distributed post-lesson survey and its results, and author reflections of the lesson.

Previous work

Hekert offers a formal definition of macroethics after reviewing and combining several engineering ethics frameworks: "'macroethics' applies to the collective social responsibility of the [engineering] profession and to social decisions about technology" [5, p. 373]. Although historically macroethics has been lacking in undergraduate engineering [2]–[5], some universities have now been introducing successful macroethics into their coursework and helping students to better understand their implications of their engineering work to society [2], [6]–[11].

We based this lesson on a similar macroethics lesson that Proessor Aaron Johnson had led twice at his previous institution, the University of Colorado Boulder. This was the first attempt to integrate macroethics content into the aerospace curriculum at this institution, and we executed a post-lesson survey to improve future iterations.

Context about the course

We taught our macroethics lesson in a junior-level spacecraft dynamics course at the University of Michigan. The course offers an introduction to the dynamics of spacecraft with a primary focus on the design and analysis of orbital trajectories and maneuvers based on the two-body problem. Course content also includes introductions to more advanced topics in spacecraft dynamics such as the three-body problem, linear orbit theory, orbital perturbations, low-thrust maneuvers, solar sails, attitude dynamics, and momentum management. Professor Oliver Jia-Richards was the course instructor and Megan Ennis was the teaching assistant for the course. There were 104 students enrolled. We chose to do the macroethics lesson for this course not only because Professor Oliver Jia-Richards was interested in collaborating with our engineering education research group, but because the course is a required space-track aerospace course. Because it is so math-heavy and "technical," adding the macroethics component to this course demonstrated how much Professor Oliver Jia-Richards and our group both believe in and want to stress the socio-technical nature of engineering. This has not historically been an emphasis in technical courses [2], [4], [5], [7] and we believe that adding this lesson highlighted the importance of macroethics.

Macroethics lesson on orbital debris

Building off of a prior macroethics lesson at University of Colorado Boulder, the goal of the lesson was for students to gain the confidence and tools to discuss macroethics in aerospace engineering. More specifically, the goal was to understand that there are a variety of perspectives on any given issue and that power and positionality affects how people think about these issues. As the dominant aerospace engineering culture is created by those with power, this lesson gave an opportunity for marginalized viewpoints to be acknowledged and respected.

To achieve this learning goal, we used orbital debris as an example to introduce macroethical discussion as well as the concepts of stakeholders[1], positionality, and ethical lenses. We chose the topic of orbital debris because it aligns well with the course material on orbit dynamics, and because the topic is less controversial compared to other topics like the military-industrial complex, for example. The aerospace industry widely agrees that orbital debris is an issue, but conflict starts when deciding who should do what to solve the problem [16]. The lesson was designed to introduce students to the exploration of macroethics without pushing them to a 'panic zone' in which they would disengage and shut down [17]. Future lessons will build on their confidence by presenting more disputed topics.

A table outlining the agenda of the 80-minute macroethics lesson is provided in Appendix A. While students walked into the classroom (a large lecture hall with stadium-like seating and desks), we presented what we called the "hook." We projected a paragraph-long issue brief on

[1] The authors note that they learned post-lesson and wish to help educate others that "stakeholders" is not a respectful term for "interested parties." Jennifer Tauli Corpuz, from the Kankana-ey Igorot People of Mountain Province in the Philippines, and Stanley Kimaren ole Riamit, an Indigenous peoples' leader from the Pastoralists Maasai Community in southern Kenya, write a blog on how they are rights holders of their land, not stakeholders that need to negotiate their priorities [12], therefore making "stakeholders" a colonial and violent word for indigenous peoples. This change in language has also been adopted by the Center for Disease Control, Indigenous Corporate Training, and Lake Superior State University [13]–[15].

the topic of satellite-mega constellations, which are groups of satellites that operate together to cover a vast span of the planet. We also presented an opening question: "Who do you think will be affected by satellite mega-constellations?" This question asked students to consider *stakeholders* without using this specific word, because we wanted to make the question accessible for all students before defining it within our lesson. Although we had previously announced to the class that we would be holding the macroethics lesson, this hook also let students know what to expect when joining class and warmed them up to the topic. We shared the question again later in the lesson after introducing the concept of macroethics.

When class officially started, Professor Oliver Jia-Richards reiterated the importance of the macroethics lesson and introduced Professor Aaron Johnson and Elizabeth (Betsy) Strehl. Professor Aaron Johnson went over the learning goals and lesson outline, which consisted of alternating periods of discussion and lecture. Students discussed the mega-constellation example that was initially projected as students walked in and then received a lecture that introduced the topics of macroethics, positionality, and ethical lenses. They then participated in a second discussion on how various ethical lenses suggested different solutions to the issue of space debris, and then listened to a closing statement on background and experiences[2]. The lesson concluded with a survey to improve future lessons and measure how well we achieved our learning goals.

The first set of discussions was organized as a "think, pair, share," during which students thought on their own silently for a few minutes, then paired up with people around them to discuss in small groups, and finally were brought back to a large group discussion. The questions we asked students to consider were related to the mega-constellation issue brief we shared earlier:

- *What is a stakeholder?*
- *What types of stakeholders benefit from mega-constellations? Why?*
- *What types of stakeholders detriment from mega-constellations? Why?*
- *Were there any stakeholders that you had not originally considered?*
- *How do you think someone's background and experiences affect their opinion about mega-constellations?*

After the first set of discussions, Aaron led a lecture that introduced the concepts of macroethics, the importance of individual background and experiences, and ethical lenses. Aaron defined ethics [18], then discussed the difference between microethics and macroethics [5]. He motivated the discussion of macroethics by providing examples of how the products of aerospace engineering have affected society in positive and negative ways. Positionality was later explicitly defined as background and experiences [19], along with critical analysis of the effects of power between persons [20]. He commented on student gender, race, and socio-economic status (SES) demographics within aerospace engineering from a large, public, research-intensive university in the Midwest [21]. We added this component of the lesson because some students do not believe in, nor consider important, the disparities in representation that exist within their program. For

[2] "Background and experiences" was a replacement definition for positionality in the beginning of the lesson. We chose not to say positionality until later because we did not want students to disengage after hearing what they may consider a progressive buzz-word.

example, how aerospace engineering is a largely white, male, dominated field. Lastly, Aaron explained norms for safe future discussions. These included:

- *Remember that other people who disagree with you may have different values, experiences, and information than you*
    - *Don't just dismiss another student who disagrees with you*
    - *Listen to what they say about their opinion and positionality*
- *Try to think about how your own positionality is influencing your perspective, especially if you're privileged in some aspect of your identity*
- *Don't feel that you must agree with everyone else*

Next, we offered students five minutes to search online for the definitions of different ethical lenses as the "think" part of the following "think, pair, share." We gave some websites to start guiding the search. Students then shared in small groups and debriefed in the large group about the ethical lenses they learned. In the lecture, Betsy specifically defined four ethical lenses: *utilitarianism*, *contractarianism*, *virtue theory*, and *justice*. We then posed another question to the whole class, asking, "How do you think each ethical lens would approach the issue of orbital debris?" This question resulted in an active discussion that filled the remainder of the class period. More details on how each instructor perceived the lesson's implementation can be found in the authors' reflections below.

The last three components of the lesson consisted of sharing the United States's current solution to the issue of orbital debris (the federal government has adopted a 5-year deorbit mandate [22]), a closing reflection on the prompt "How do you think someone's background and experiences affect their ethical lens?", and a post-lesson survey.

Out of 104 students enrolled in the course, 33 students attended the macroethics lesson and 18 students completed the post-lesson survey. Although Oliver and Megan advertised the importance of the macroethics lesson beforehand, the low attendance for both the macroethics and regular lessons may be due to students believing that the social components of engineering are not relevant to their technical education [1].

Or, this level of attendance may just be a product of national student attitudes toward in-person attendance post-COVID [23]. During other "technical" class periods, there were typically 40 students present in person. Oliver noted a reason for low attendance as the fact that lectures were recorded and he posted typed notes. Students complete individual assignments and exams and learn the technical content through lectures on the whiteboard or online. There is no collaboration during or outside of class that would require participation.

However, the way we presented our macroethics lesson through small and large group discussions contrasts how the spacecraft dynamics course was structured to be feasible individually. We wanted students to consider the social contexts of engineering through talking with others, which needed attendance. Teaching our macroethics lesson through discussions helped to change students' understandings of the course from individualistic to collaborative, and also from purely technical to socio-technical.

Post-lesson survey

Out of 33 students who attended the lesson, 18 students completed the survey (54% of students in class and 17% of students in the course). Unfortunately the survey was given during the last two minutes of the lecture period even though it is estimated to take 10 minutes, so a lesson learned is to give enough time in the future. We also advertised the survey through an online class announcement to get more responses. Students took an average of 12 minutes to take the survey. After a consent and information page, students wrote an anonymous ID so we may track responses across future surveys. There were nine Likert scale questions (providing quantitative data) and three open-response questions (providing qualitative data). All results are shown in Appendix B.

Four out of the nine multiple choice questions attempted to evaluate and quantify how well we achieved our learning goals. One question asked if students learned about the impact of aerospace systems on society, and one question asked the degree to which students saw ways in which their personal values were reflected in the ways they viewed stakeholders. Another asked students if they felt more prepared to discuss aerospace ethical issues having participated in the lesson. The last two questions asked students if they enjoyed the lesson and if they would like to have more lessons like this in the future.

The results from the first four questions, presented in Figures 1 - 4 below, showed that students who completed the survey generally believed that they did learn about the topics covered in the lesson. However, one student did not believe they learned something about orbital debris. There were also two students who disagreed that they learned something about positionality. These students' open-response questions did not explain why they disagreed that they learned those topics, so we assumed that they did not learn more because they were already familiar with the material presented.

Figure 1: I learned something about orbital debris

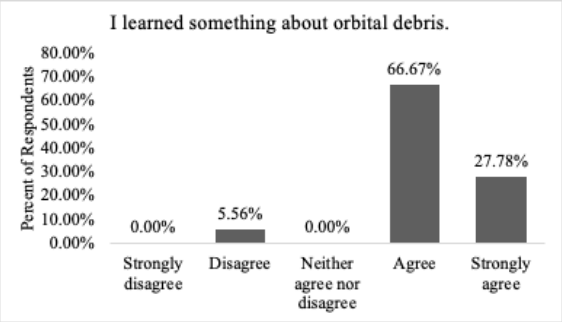


Figure 2: I learned something about ethical lenses

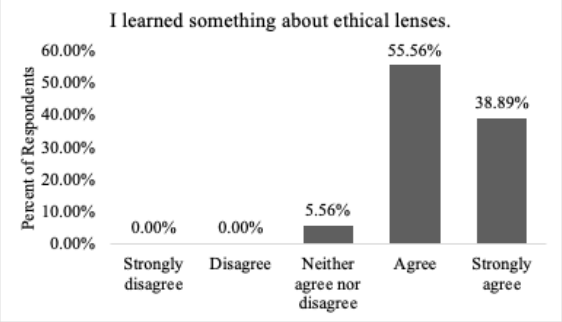


Figure 3: I learned something about positionality

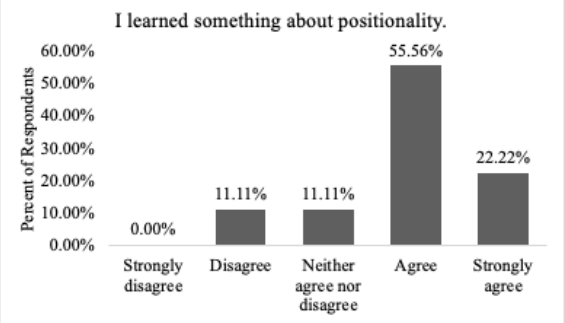


Figure 4: I learned something about stakeholders

Students who completed the survey also agreed and strongly agreed that they saw ways in which aerospace systems impact society, and that their personal values were reflected in the ways they assigned importance to stakeholders. This is shown in Figures 5 and 6 below.

Figure 5: I learned about the impact on society

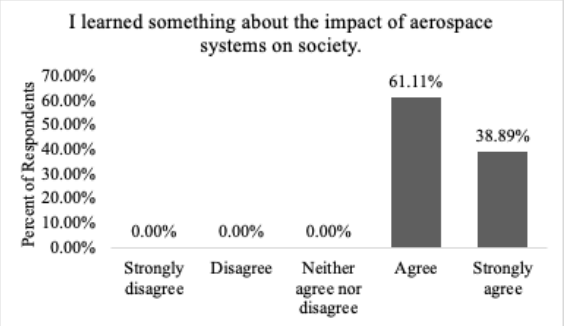


Figure 6: I saw my personal values reflected

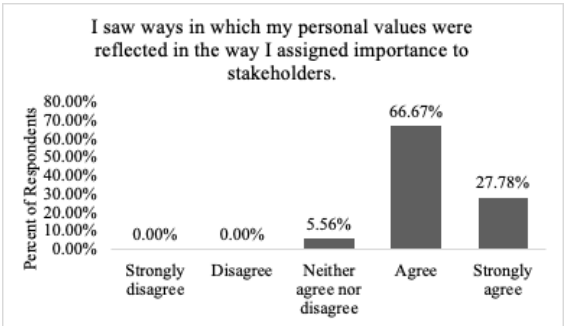
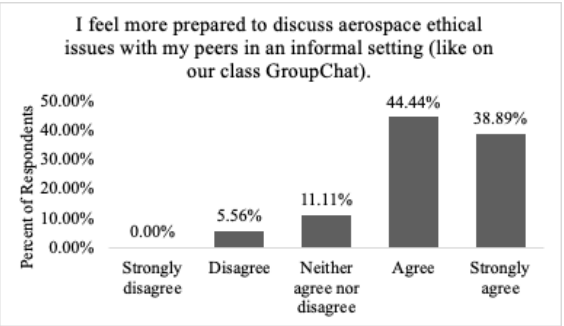


Figure 7 below demonstrates that students also generally felt more prepared to discuss aerospace ethical issues with peers in an informal setting (like in an online class group chat) having participated in the lesson. One student did not report feeling more prepared to discuss aerospace ethical issues. We are unsure why this was the case but we hypothesize that this lesson may have been their only exposure to aerospace macroethics and that more lessons are needed to support this student's learning.

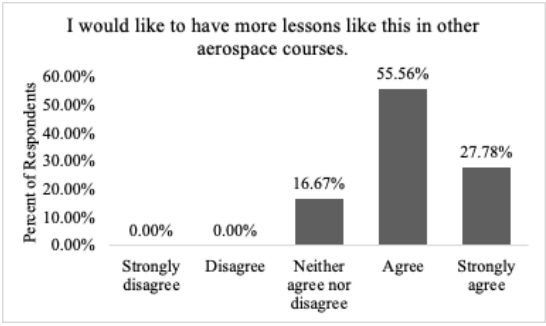
Figure 7: I feel more prepared to discuss



All students who filled out the survey answered that they did enjoy the lesson and would like lessons like this in other aerospace courses, which is a very encouraging result for our research team. This is shown in Figures 8 and 9 below.

Figure 8: I enjoyed today's lesson

Figure 9: I would like to have more lessons



For each of the three open-response questions, there were six student responses. The first question asked students to describe anything they found surprising about the lesson, and two students noted that they had had little ethics education before. One student was intrigued by the complexity of the Kessler Syndrome.[3] Perhaps the idea of noting the technical complexities involved in macroethical issues inspired them, and another noticed how nuanced the issue of orbital debris is. Lastly, one student was surprised by how difficult it is to think of a solution in spite of everyone agreeing that orbital debris is a problem, and another enjoyed hearing the input of others. The second question asked about other macroethics topics students were interested in learning about, and a few examples students gave were learning about the environment, nuclear power, their professional choices and professionalism, space territorialization and resource extraction. Three students suggested discussing the environment, a popular topic. The third question asked for any other feedback, and we interpreted the responses as appreciative and interested in more macroethics lessons in the future.

Even though the responses to the Likert and open-response questions were overall positive, we do not wish to assume this quality of response to all students present at the lesson or enrolled in the course. Only half of the students who were in the class that day took the survey, which was 17% of the students enrolled. An important lesson learned for future macroethics implementations is to give students plenty of time to complete the survey. Leaving students to fill out the survey on their own time outside of class not only greatly reduced the response rate, but also likely skewed the results to the opinions of students internally motivated to fill out the survey because they believe macroethics is important and want more exposure.

Reflections

Included are several personal reflections on the macroethics lesson to serve as a guide on what future educators may expect if they were to develop and implement their own. As Aaron taught in the lecture component of the macroethics lesson, positionality and power impact how people perceive the world based on how the world treats them [19]. Or, from a feminist perspective,

[3] The Kessler Syndrome explains that when orbital debris collides and breaks apart with other debris, the likelihood of more collisions increases severely, like a runaway chain reaction or collisional cascading [24].

knowledge cannot be separated from the knower, and knowers hold different types of validated power [25]–[28]. Recognizing how knowledge is affected between persons (both how it is produced and received) is useful because it allows for an understanding that engineering education is another product of power relations [20]. Adding our reflections actively works against the de-politicization of engineering education [1] by sharing our power and positionalities that influence our work. Hopefully this helps other educators understand how their positionality and power affect their work if they were to develop and implement their own macroethics lessons.

Everyone involved in implementing the lesson believed that it went well and should be more frequent. The lesson created a space for great discussion, but led to time management challenges. There was also a student who appeared to reject the lesson by shaking their head and not participating in discussion, yet other students seemed content to be involved. Lastly, we considered how our background and experiences informs our commitment to social justice in engineering education.

Megan Ennis, Co-Facilitator and Course TA

Positionality. Overall I am proud of myself for standing in front of students to take a leadership role. My goal was to execute the lecture for the first time and take feedback to better improve the next iteration, which we completed. As someone who holds a commitment to social justice and an identity as a woman in engineering, simply taking time to do the macroethics lesson challenges the definition of undergraduate engineering. Additionally, Oliver inviting us to do the lesson in the heavy technical course demonstrates a growing agreement to reflect social justice in aerospace not only to the students, but to the department and field as a whole.

Reflection. As we were setting up the lecture, we left the initial mega-constellation prompt on the projector as students entered and settled in. One student made what I considered to be a casual joke about the lecture– they asked if it was going to be an “Elon roasting session.” The prompt did not mention Starlink nor Elon Musk, but I was interested in how the class would go based on how comfortable the student felt to start a conversation. Aaron responded that we’re here to facilitate discussion and not force our own opinion.

When it was my turn to lead the stakeholder discussion, I stood stiffly and had to manually tell myself to move across the room. When asking for student responses, I forgot my active listening skills and had trouble not only building on but remembering what others said. However, the second discussion felt more organic as I grew more confident. Even though we started ahead of schedule, I lost track of time and ended up losing a few minutes for the feedback survey. Students were building on each other, new questions were being asked, and there was broad participation. We held back from emphasizing the effect of positionality when we first introduced it because we would repeat the statement during this last question, but unfortunately we could not discuss it there either.

Betsy Strehl, Engineering Education Research Ph.D. Student

Positionality. In regards to my positionality, my identities have always influenced that way that I perceive engineering and its implications. However, I was unable to recognize how differing identities change people's perspectives nor how to articulate that properly until late in my undergraduate career. As a white, first-generation, queer, neurodivergent woman; I am able to recognize that there are certain spaces that were built for me and others that were not. I have worked to understand my own intersecting privileged and marginalized identities, and held a lot of anger towards institutional power structures that often fail minoritized communities. I do feel comfortable questioning engineering culture and honestly would like to use my power and privilege to change it to help improve the experiences of future generations of students. As change occurs slowly, my personal struggle involves directing my passion and energy pragmatically in order to avoid burnout and frustration. I hope that I can use my experiences to advocate for change and bring in voices that I cannot speak for using the power that I do have.

Reflection. When we were setting up the lesson, I noticed that not a lot of students read the guiding prompt on the board, but were more focused on chatting with each other. In hindsight, we should have dedicated a bit of time into the lecture for this if we really wanted to prime students for the lesson. While there were a few students discussing the prompt, I did see a particular student roll their eyes regarding the question and shrug before moving on.

Introduction started well and I think the students appreciated knowing that Aaron could potentially be their instructor in senior-level capstone design courses instead of a random person. The way he approached the topic was very engaging and helped the students warm up a bit. When the discussion began with Megan, students were a bit slow to respond, but I think that could have been for a lot of reasons. Megan said that she was feeling nervous, and it showed slightly based on the way she initially responded to student answers, but she warmed up quickly and improved significantly! Initial student responses when it came to naming stakeholders were very superficial, only naming the most obvious and immediately affected group of stakeholders without thinking about broader implications of orbital debris. I think that the students' initial responses were because they were unsure about the direction of our discussion. When they realized that we weren't there to patronize them and we weren't looking for right or wrong answers, engagement increased.

During Aaron's lecture, students seemed to really connect when he began showing students all the different examples of ethical issues in aerospace. However, the tone switched slightly when the conversation shifted towards the demographics of the department and the concept of power and privilege. I specifically began watching the students during this time and noticed a few students disengage slightly. One specifically (white male), sat alone despite a prompt to sit by others and narrowed his eyes and shook his head repeatedly while Aaron spoke. I think that the mood changed for a few reasons, one being that the tone of the discussion changed and students were unsure of how to respond. As the majority of the class was white and male, students may have been unsure if they were going to be lectured about diversity or "under attack". Also, students may have felt uncomfortable because Aaron was asking the students to recognize how their privilege affects them, which is an inherently uncomfortable process. I would like to explore this topic further in future iterations of the lesson if time allows for it. It might be better

to explain upfront why we are showing any slides about the demographics of the department so students really understand why it's important ethically.

When Aaron took over again for the ethical lens discussion, the students were fairly quiet in the beginning. I was worried that we would lose the students' interest, but when we added in a brief "think, pair, share" activity, the students seemed to speak with one another quite a bit. The class had a great discussion following that, which was much deeper in nature applying the ethical lenses to the topic of orbital debris. I really appreciated the variety of students responding and the depths of the answers provided. Also, no conclusions were necessarily decided by us or the students as to which lens was ideal, which was ultimately a goal for the lesson.

The conversation about ethical lenses was actually so good that we ended up losing time for our final conversation about how someone's background would affect how they view the orbital debris situation. We got a few good answers, but I would have liked to spend more time on that discussion! Same goes for the survey as well, hopefully if we include more in-class time our post-survey numbers will increase.

Professor Aaron Johnson, Co-Facilitator

Positionality. When I was an undergrad in aerospace engineering at Michigan, I did very well. I just wanted to do math, I didn't want to build anything or even know why we were doing math. This is how the courses were–and still are, generally–taught at Michigan, so I did well. I had no reason to question this culture or curriculum. And, as a white man who had always been around a lot of people who looked and thought like me, I had fewer reasons to question the culture. Since getting into engineering education research I have come to more of an understanding of other people's experiences in engineering and I have learned other frameworks, and so I have been able to look at engineering culture with a more critical perspective. I can see the ways in which our aerospace curriculum is minoritizing certain students because of their identity–or even their epistemology. So, I want to make those minoritized students' experiences better by changing the system. And, I still think there are a lot of students who are like me and aren't questioning the culture. I want to put pinpricks into that bubble to start deflating it. I want these students to recognize that they're privileged and that their experience is not everyone's experience. I want to bring in aspects of engineering judgment and macroethics and power and privilege so they know that aerospace doesn't exist in an apolitical vacuum. So that's my positionality–a convert from an unquestioning part of the system to someone who wants to reform the system. And, my power and privilege can be an asset now, because I can use it to get the white male students to listen and reflect.

Reflection. I thought the lesson went really well, and at the end I was quite happy with how it went. We had the initial discussion question about mega-constellations on the front screen while students were coming into class, but I don't believe anyone discussed this question. Or, at least, I didn't hear anyone. I did hear two students chatting about the orbital debris issue brief, and I remember one saying that they read it but didn't remember all of it. That's fine!

Megan did really well facilitating the first few questions about stakeholders–she said that she was nervous but I didn't sense that. Students all participated really well in these first activities,

and really in all the activities. They talked in their groups pretty freely and appeared to stay on task. And then, when there were opportunities to share out, a lot of different groups shared. Like, there were the "usual suspects" in that a few students talked more than others. But, there were a lot of different students who shared during the whole lesson.

I thought that my section of the lecture was pretty good. I still found it difficult to stand in front of students in a technical course and talk about power and privilege. I don't know why; I feel pretty confident in my beliefs and knowledge of the concept of power, and I'm pretty open about it in everyday conversation. But there's just something about being in a formal class, in front of students, and talking about power. Maybe I was worried about the reception from students who didn't want to consider that they're privileged. And, as Betsy said, there was at least one white male student who kind-of narrowed his eyes at this whole discussion and didn't engage. But nobody, like, said anything to me. I did try to use myself as an example in talking about my power and privilege, but I hope it got students thinking, too. The slides on the department demographics were ok– I thought they felt a bit shoehorned in, but the content is important. It's probably stuff that students are aware of on some level, but I imagine that the numbers help make clear the white male dominance of the aerospace field.

The section on ethical lenses was the part that I was most worried about in-the-moment. I remember thinking that we were deep in the ethical weeds, and that we weren't relating to aerospace engineering at all. So I was worried about losing students. There wasn't really evidence that we were losing students; they did seem to be doing the activity and going to the website we provided to look at different lenses. And when we asked people to share out they did! So, that's all good evidence that students were still engaging. They must have trusted that this ethics content would be made relevant to orbital debris, which is great. In the future we should make that explicit–like, present the question of "What do you do about orbital debris?" and then say that ethical lenses provide different answers to this question. Then go to the ethical lenses.

Once we got to the end, the last discussion was amazing. It was awesome. A lot of different students shared, and I think we did a really good job showing the complexity of these issues. I feel that we didn't answer the issue at all (which we didn't intend to do), but instead we ended up posing more unanswered questions. Students did a good job trying to apply the ethical lenses to orbital debris, although I noticed that their knowledge of the ethical lens was generally limited to the one sentence on our slide. Like virtue ethics being the midpoint between extremes. That makes sense–we only gave them 5 minutes to learn ethics! But just a note that we have to be aware of this. I chimed in once with something about utilitarianism (the ends justify the means), and gave a bad example of how it might apply to orbital debris. But, another student chimed in with a better example right after me, so I was happy. Lastly, I think that there was some good scaffolding comments that we made during the activity that we should make before next time– 1) the facilitation team isn't experts on ethical lenses; we're learning with the students, 2) we're giving a very, very brief overview of ethics, 3) it's ok if you don't fully understand these ethical lenses. Things like that.

So overall I was happy with the lesson! I'm also excited to have students go deeper into different spaceflight issues in space systems design next semester, as many of the students in spacecraft dynamics will take this senior projects course with me. I hope that they'll remember this

introduction so we can start a bit down the runway, to mix my aviation and spaceflight metaphors. I suppose we'll see!

Professor Corin (Corey) Bowen

Professor Corey Bowen did not attend the lesson, so she did not write a reflection.

Professor Oliver Jia-Richards, Course Instructor

As the regular instructor for the course, I was quite pleased with how the macroethics lecture was implemented. The students seemed quite engaged in terms of answering the different prompts, and it was great to see students that didn't normally talk in class provide their input. There are improvements that I believe could be made in order to better integrate the lecture into the overall course content such as increasing the number of connections to space-related topics. In addition, expanding the issues to topics beyond just space debris could help students see the broader implications of the lecture. It may also be beneficial to hold the lecture earlier in the semester so that I can make reference to it throughout the rest of the course.

Multiple students commented to me afterwards that they enjoyed the macroethics lecture as well as the change of pace relative to the regular course content. While the macroethics lecture was certainly different in style to the other lectures in the course, I would like to see a macroethics lecture become part of the "regular course content" moving forward. During other lectures in the course I have made reference to some of the ethical issues related to space missions (e.g. planetary protection for interplanetary missions), but these references did not—and could not—go to the same depth as a dedicated macroethics lecture.

Conclusion and Future Work

A macroethics lesson on orbital debris was implemented within a junior level spacecraft dynamics course, and the biggest takeaway is that we facilitated a space for critical discussion, which positively resulted in a critical discussion. Future lessons should not only give enough time for students to take the survey to get results more representative of the class, but replicate and build on the lesson successes presented in this paper. Out of the 17% of students in the course and 54% of students in class that day that completed the survey, almost all respondents reported progress on their learning of the topics we covered and the feedback was overall positive. The goal of the overarching research project is to encourage a restructuring of aerospace engineering to incorporate macroethics throughout students' undergraduate career, and this intervention is a stepping stone toward changing classroom 'cultural spaces' [1]. Our future (now current) work consists of implementing macroethics into a senior level spacecraft design course not just once, but throughout the semester and creating a research-free macroethics club outside of class for students to opt-in for more discussions. Future work for next year consists of working with additional aerospace faculty members to implement macroethics into other undergraduate courses. This research is important because integrating discussions of power within technical aerospace courses draws engineering out of a positivist and meritocratic mindset and can help move toward a reconstruction of science and engineering that is founded in justice.

Acknowledgements

The authors would like to thank previous students Raymie Fotherby, Jasmine Chadha, and Andrew Benham, and Professor John Mah for their work at University of Colorado Boulder. Their boldness and determination to change the culture of their engineering department to be more inclusive built the foundation of this research. Their continued involvement is greatly appreciated.

References

[1] E. A. Cech, "The (Mis)Framing of Social Justice: Why Ideologies of Depoliticization and Meritocracy Hinder Engineers' Ability to Think About Social Injustices," *Engineering Education for Social Justice: Critical Explorations and Opportunities*. Springer Netherlands, Dordrecht, pp. 67–84, 2013. [Online]. Available: https://doi.org/10.1007/978-94-007-6350-0_4

[2] A. Colby and W. M. Sullivan, "Ethics Teaching in Undergraduate Engineering Education," *J. Eng. Educ.*, vol. 97, no. 3, pp. 327–338, 2008, doi: https://doi.org/10.1002/j.2168-9830.2008.tb00982.x.

[3] A. Benham, R. Fotherby, A. Johnson, and C. Bowen, "Student Perspectives of Aerospace Engineering Macroethics Issues and Education," Oct. 2022, pp. 1–5. doi: 10.1109/FIE56618.2022.9962654.

[4] A. R. Bielefeldt, M. Polmear, C. Swan, D. Knight, and N. Canney, "An overview of the microethics and macroethics education of computing students in the United States," in *2017 IEEE Frontiers in Education Conference (FIE)*, 2017, pp. 1–9. doi: 10.1109/FIE.2017.8190445.

[5] J. R. Herkert, "Ways of thinking about and teaching ethical problem solving: Microethics and macroethics in engineering," *Sci. Eng. Ethics*, vol. 11, no. 3, pp. 373–385, Sep. 2005, doi: 10.1007/s11948-005-0006-3.

[6] N. A. Andrade and D. Tomblin, "Engineering and Sustainability: The Challenge of Integrating Social and Ethical Issues into a Technical Course," 2018.

[7] A. Benham *et al.*, "Developing and Implementing an Aerospace Macroethics Lesson in a Required Sophomore Course," in *2021 IEEE Frontiers in Education Conference (FIE)*, 2021, pp. 1–9. doi: 10.1109/FIE49875.2021.9637172.

[8] A. Gupta, "A Practitioner Account of Integrating Macro-ethics Discussion in an Engineering Design Class," Jul. 2017. doi: 10.18260/1-2–27498.

[9] B. Jimerson, E. Park, V. Lohani, and S. Culver, "Enhancing Engineering Ethics Curriculum by Analyzing Students' Perception," Jun. 2013, p. 23.530.1-23.530.15. doi: 10.18260/1-2–19544.

[10] Palmer, Emily, Tawney, Jacqueline, and Weaver, Jennifer, "A Model for Student-led Development and Implementation of a Required Graduate-level Course on History, Ethics, and Identity in Aerospace Engineering," presented at the ASEE Annual Conference & Exposition, Minneapolis, MN: ASEE, Aug. 2022. doi: https://peer.asee.org/40748.

[11] D. G. Wareham, T. P. Elefsiniotis, and D. G. Elms, "Introducing ethics using structured controversies," *Eur. J. Eng. Educ.*, vol. 31, no. 6, pp. 651–660, 2006, doi: 10.1080/03043790600911712.

[12] "We Indigenous Peoples are Rights-Holders, not Stakeholders," *Inter Press Service*, Dec. 08, 2022. https://www.ipsnews.net/2022/12/indigenous-peoples-rights-holders-not-stakeholders/ (accessed May 01, 2023).

[13] "CDC's Health Equity Guiding Principles for Inclusive Communication," *Centers for Disease Control and Prevention*, Nov. 03, 2022. https://www.cdc.gov/healthcommunication/Preferred_Terms.html (accessed May 01, 2023).

[14] B. Joseph, "9 Terms to Avoid in Communications with Indigenous Peoples." https://www.ictinc.ca/blog/9-terms-to-avoid-in-communications-with-indigenous-peoples

(accessed May 01, 2023).
[15] Banished Words List Archive December 2021 Archived, Lake Superior State University. https://www.lssu.edu/traditions/banishedwords/archive/ (accessed May 01, 2023). See year 2016.
[16] "Orbital Debris." https://sma.nasa.gov/sma-disciplines/orbital-debris (accessed Feb. 28, 2023).
[17] C. Bowen *et al.*, ""The Development and Implementation of 'Class Community Norms' to Facilitate Learning in a Social Justice-Oriented Classroom," Oct. 2022, pp. 1–9. doi: 10.1109/FIE56618.2022.9962392.
[18] Velasquez, M, Andre, T, and Meyer, M.J., "What is Ethics?," *Markkula Center for Applied Ethics*. https://www.scu.edu/ethics/ethics-resources/ethical-decision-making/what-is-ethics/ (accessed Feb. 28, 2023).
[19] L. Sánchez, "Positionality," *Encycl. Geogr.*, pp. 2258–2258, 2010.
[20] D. Riley, "EMPLOYING LIBERATIVE PEDAGOGIES IN ENGINEERING EDUCATION," *J. Women Minor. Sci. Eng.*, vol. 9, pp. 137–158, 2003.
[21] D. C. L. Bowen, "Critical Analyses of Representation and Success Rates of Marginalized Undergraduate Students in Aerospace Engineering," 2021.
[22] "FCC Adopts New '5-Year Rule' for Deorbiting Satellites," *Federal Communications Commission*, Sep. 29, 2022. https://www.fcc.gov/document/fcc-adopts-new-5-year-rule-deorbiting-satellites (accessed Feb. 28, 2023).
[23] G. Kortemeyer, N. Dittmann-Domenichini, C. Schlienger, E. Spilling, A. Yaroshchuk, and G. Dissertori, "Attending lectures in person, hybrid or online—how do students choose, and what about the outcome?," *Int. J. Educ. Technol. High. Educ.*, vol. 20, no. 1, p. 19, Mar. 2023, doi: 10.1186/s41239-023-00387-5.
[24] J. Corbett, "Micrometeoroids and Orbital Debris (MMOD)," *NASA*, Sep. 17, 2015. http://www.nasa.gov/centers/wstf/site_tour/remote_hypervelocity_test_laboratory/micrometeoroid_and_orbital_debris.html (accessed Feb. 28, 2023).
[25] K. Barad, "Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter," in *A Feminist Companion to the Posthumanities*, C. Åsberg and R. Braidotti, Eds., Cham: Springer International Publishing, 2018, pp. 223–239. doi: 10.1007/978-3-319-62140-1_19.
[26] D. Haraway, "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective," *Fem. Stud.*, vol. 14, no. 3, pp. 575–599, 1988, doi: 10.2307/3178066.
[27] S. G. Harding, *The Feminist Standpoint Theory Reader: Intellectual and Political Controversies*. in The Feminist Standpoint Theory Reader: Intellectual and Political Controversies. Routledge, 2004. [Online]. Available: https://books.google.co.uk/books?id=qmSySHvIy5IC
[28] N. C. M. Hartsock, "The Feminist Standpoint: Developing the Ground for a Specifically Feminist Historical Materialism," in *Discovering Reality: Feminist Perspectives on Epistemology, Metaphysics, Methodology, and Philosophy of Science*, S. Harding and M. B. Hintikka, Eds., Dordrecht: Springer Netherlands, 1983, pp. 283–310. doi: 10.1007/0-306-48017-4_15.

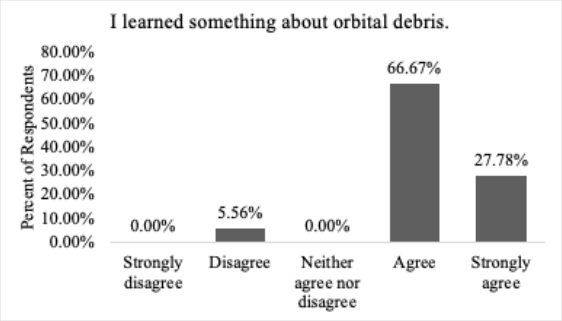
Appendix A - Macroethics lesson plan

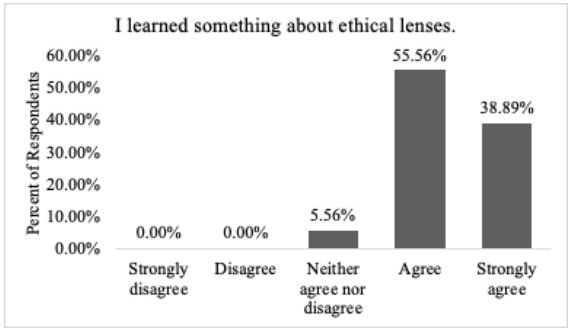
Learning Objectives:	Students will be able to gain confidence and tools to discuss macroethics in aerospace engineering a. Understand that there are a variety of answers b. Understand that positionality and power influence how people think about these issues

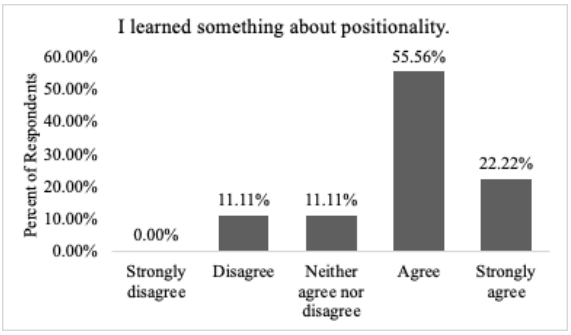
Section Name	Lesson Activity	Time Length
Hook	Issue Brief of Satellite Internet Service Opening Question: ● *Who do you think will be affected by satellite mega-constellations?*	Before class starts
Introduction	Course instructor, Professor Oliver Jia-Richards, introduce importance of lesson and macroethics facilitator, Professor Aaron Johnson (with personal spin) ● Professor Aaron Johnson is another professor in our aerospace engineering department ● He does engineering education research ● This lesson is important to understand that what we do as engineers not only affects our projects but the world socially as well ● Professor Aaron Johnson will teach spacecraft senior design next semester	1:30pm -(5min) 1:35pm
Hook Discussion (Whole Class)	Define Stakeholders Discussion Questions: ● *What is a stakeholder? Is there anyone we left out of the opening question?* ● *What types of stakeholders benefit from mega-constellations? Why?* ● *What types of stakeholders detriment from mega-constellations? Why?* ● *How do you think someone's background and experiences affect their opinion about mega-constellations?*	1:35pm - (20min) 1:55pm
Lecture 1	Introduction to Macroethics, Positionality (background and experiences), and Ethical Lenses	1:55pm -(20min) 2:15pm

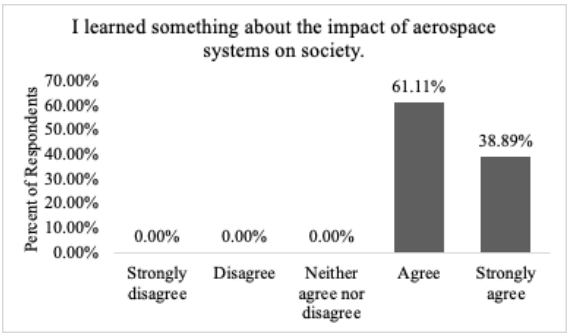
Discussion (Think, Pair Share and Whole Group)	Students do a brief introductory search about ethical lenses [a starting website is shared with students] ● *Discuss with partner the lenses you discovered and what they are* Share lenses found and identify key aspects with the class We will focus on utilitarian, contractarian, justice, and virtue Megan Ennis will present the scenario of space debris and facilitate a full-class discussion on the solution(s) suggested by each ethical lens Present U.S. solution to the scenario based on recent FCC guidelines. (Let students stew on it)	2:15pm -(20min) 2:35pm
Closing Reflection (Think, Pair, Share)	Students discuss with other partner the following reflection: ● *How do you think someone's background and experiences affect their ethical lens?*	2:35pm (10 min) 2:45pm
Survey	Survey link is distributed and students who do not wish to participate can play around on their computer	2:45pm (5 min) 2:50pm

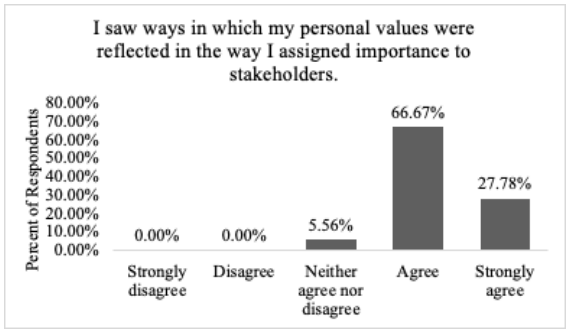
Appendix B - Post-lesson survey results

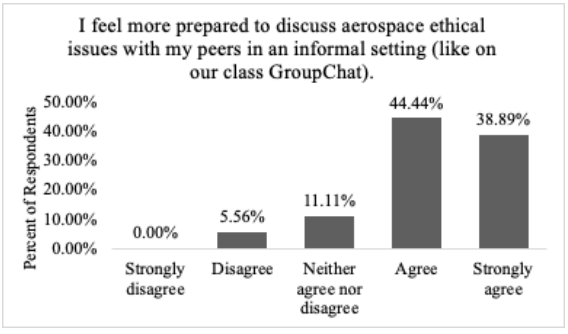


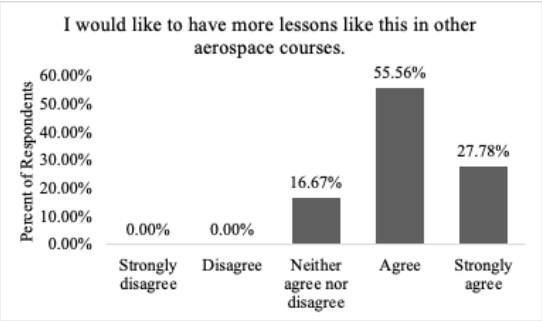












Question: Was there anything you found surprising in today's lesson?

Responses:

> *I haven't learned much about engineering ethics in my time here, so it was interesting to look at everything we are learning in an ethical sense.*
>
> *Learning about the Kessler Syndrome was a really cool topic. It's weird to think that all space infrastructure is possibly at a high risk of being damaged once the amount of space debris orbiting our planet reaches a critical point, and it's something that needs to be considered every time an object i.e rocket, satellite, etc. is launched to space.*
>
> *how nuanced the issue actually is*
>
> *I found it surprising how difficult it was to think about solutions to the problem of space debris IN SPITE of everyone agreeing that it is bad and should be minimized.*
>
> *I thought the different ethical lenses were cool, I hadn't heard of those before.*
>
> *I liked hearing the input of others in the class.*

Question: Are there other macroethics / large-scale problems in aerospace engineering that you're interested in learning about?

Responses:

> *Yes definitely, very interested in environmental effects and also how other aerospace technologies/events affect certain groups of people*
>
> *Nuclear power in space.*
>
> *It seems difficult to get a job in aerospace engineering that doesn't involve the moral dilemma of making something that may be used to cause harm.*

I think the debate about colonizing the moon/mars is interesting one. Should we be investing effort to establish permanent bases and eventually colonies on these places while there are still so many problems on Earth?

Forward contamination of planetary ecosystems during space exploration missions

Environmental impacts for both rockets and aircraft

Question: Do you have any other feedback about this lesson?

Responses:

Nice and chill! Got to talk to other students, and discuss some things that affect us all!

Nope, I thought it was great!

Just a thank you to Professor Johnson for coming in and speaking today!

This was a good chance to talk with classmates and consider impacts of the aerospace industry that extend into the societal/ethical realm.

I would love an ethics course in the aero department, I'm really interested in how people are affected

Nope