Work in Progress: Creation of a Macroethics Case Study Integrated into an Aerospace Systems Design Course

Sabrina Olson, University of Michigan

Sabrina Olson is an aerospace PhD candidate at the University of Michigan. She holds degrees in both aerospace engineering and engineering management, and has taught as a lecturer at California Polytechnic State University in San Luis Obispo. These experiences have led her to seek out a research pathway at the intersection of macroethics, space systems design, and engineering education. She is jointly advised by Dr. Oliver Jia-Richards and Dr. Aaron Johnson at the University of Michigan.

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.

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. His design-based research focuses on how to re-contextualize engineering science engineering courses to better reflect and prepare students for the reality of ill-defined, sociotechnical engineering practice. Current projects include studying and designing classroom interventions around macroethical issues in aerospace engineering and the productive beginnings of engineering judgment as students create and use mathematical models. Aaron holds a B.S. in Aerospace Engineering from Michigan and a Ph.D. in Aeronautics and Astronautics from the Massachusetts Institute of Technology. Prior to re-joining Michigan, he was an instructor in Aerospace Engineering Sciences at the University of Colorado Boulder.

Student Paper

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Sabrina Olson, Dr. Oliver Jia-Richards, Dr. Aaron W. Johnson

Abstract

Ethics and social responsibility education within aerospace engineering remains limited, with education on the subject often disconnected from technical course content and led by guest lecturers. While still valuable, this approach inadvertently signals to students that such topics are an addendum to their work as engineers, and reinforces the misconception of engineering as an apolitical field. Furthermore, existing ethical discussions place focus on the microethical realm, examining the ethical implications of individual decisions within the profession. This microethical focus, while important, overlooks the wider impact of engineering technologies on society. Contrastingly, macroethics addresses the collective social responsibility of the engineering field, emphasizing the ethical concerns of engineering technology. However, the abstract and qualitative nature of these macroethical concepts often conflicts with the more quantitative content of technical engineering classes, complicating efforts to integrate them into engineering coursework.

This work-in-progress paper presents an example of how macroethical concepts can be embedded into traditional technical classes to foster student awareness of their ethical responsibilities as future engineers. An in-class macroethics activity and follow-up assignment were implemented in an aerospace engineering capstone design course at the University of Michigan. In the in-class activity, the technical concept of spaceports, or facilities designed for spacecraft launch, and the macroethical concepts of rightsholder analysis were specifically selected to complement the course topic of spacecraft systems design. As such, the course structure was designed to present macroethical considerations as equivalent to other systems design requirements. The in-class activity encompassed a full course period and was both developed and presented by the course instructor, with the follow-up assignment appearing in the final student group reports.

The aim of the in-class activity was to increase student awareness of macroethical effects, asking the broader question of who/what is impacted when an engineering decision is made. To this end, activities of rightsholder identification and power-impact mapping were implemented, along with small-group and full-class dialogue. Students were asked to select a location for a spaceport within their university's host state, consider the impact of their choice by identifying the rightsholders affected, and compare and contrast the differences in power and impact of these

affected parties. Following the lesson, students repeated this process as part of their final course project, considering the social impacts as part of their space system design process.

The instructor's experience of developing and implementing the in-class macroethics lesson and activities is examined within this paper, with focus placed on the decisions made within course structuring and lesson planning to present macroethical content as equivalent in importance to technical content. Discussion of learning goals and pedagogy will be shared with aims to identify key aspects of the macroethics lesson that may be implemented in other courses. Future work by the authors will seek to further develop this core set of facilitation goals, and integrate student data into evaluating effectiveness of the lesson in developing students' macroethical awareness.

Introduction

As the field of aerospace becomes increasingly globalized, ethical and social responsibility education within the field must keep pace. Accreditation by The Accreditation Board for Engineering and Technology (ABET) requires undergraduate engineering curricula to provide some form of ethics education, with students demonstrating the ability 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, 2024, p.6). However, this ambiguous scope has led to varying approaches to ethics education in engineering as educators work to determine effective methods (Martin, 2021).

One approach is that of a guest lecture or seminar session, presented within a technical engineering course by a guest lecturer. Often, this approach suffers from a lack of clear connection between the ethical and technical course content. This lack of connection, and use of a guest lecturer, inadvertently signals to students that ethics and social responsibility are addendums to their work as engineers rather than integral aspects of it. Divorcing ethics from the technical content of a course reinforces the misconception of engineering as an apolitical field and fails to acknowledge both the societal impact of engineers and the influence of individual engineers themselves. This apolitical viewpoint, interwoven with the ideals of meritocracy, nullifies attempts to effectively address issues of social justice and responsibility within the field (Cech, 2013).

Furthermore, existing ethical discussions tend to place focus on microethics, which examines the ethical implications of individual decisions within the profession (Herket, 2005). Common topics explored within this microethical realm include personal integrity, safety breaches, and whistleblowing. Within aerospace courses, case studies such as the space shuttles *Challenger* and *Columbia* are frequently used to illustrate the impact of microethical decisions (Post, 2014). While important, this focus on microethics can fail to address the wider impact of engineering technologies on society, leaving students ill-equipped when it comes to considering ethical concerns at a broader, systemic level.

In contrast, macroethics addresses the collective social responsibility of the engineering field (Herket, 2005). Concepts such as technological sustainability and dual-use technologies that can be used both for civilian and military purposes fall within this realm, and emphasize the social impact and ethical concerns of technical engineering decisions. Aerospace companies must navigate such macroethical concerns in their work, such as the case of SpaceX's Starship launches and their resulting conflicts with the FAA and EPA (Foust, 2023; FAA, 2024). However, the abstract and qualitative nature of these macroethical concepts often conflicts with the more concrete and quantitative content of technical engineering classes, complicating efforts to integrate them into coursework.

This work-in-progress paper presents an in-class macroethics activity and follow-up assignment taught within an aerospace engineering capstone design course at the University of Michigan as an example of how macroethical concepts can be embedded into traditional technical classes to foster student awareness of their ethical responsibilities as future engineers. The goal of such an embedded macroethical lesson is not to provide students with a playbook of guidelines but rather to foster awareness, understanding and critical thinking to better prepare them to navigate macroethical dilemmas in the real world. This course was taught by the third author, and he discusses his experience in this paper to provide insight into how macroethical content was developed for an embedded into a technical aerospace course. Further research will incorporate analysis of student data to draw more definitive conclusions on lesson effectiveness; such results are deferred to future research publications.

Course Description

The macroethics lesson described in this work-in-progress paper was developed for a capstone design course for senior aerospace students at the University of Michigan. Students can choose between an aircraft design course offered every fall or space systems design course offered every winter. This paper focuses on an offering of the space systems design course taught by the third author. Within the course, students learn the core principles of space systems design and work together in teams to design a space mission concept, delivered as a final report at the conclusion of the course. In the semester discussed in this paper, 87 students were enrolled in the course.

The course is designed to satisfy ABET Student Outcomes 1-7. Specifically, the primary learning objectives for the course were listed as teamwork, communication, analysis/design, technical issues, design process, nontechnical drivers, industry-level rigor, professional exposure, and macroethics. Each learning objective was expanded upon in the syllabus; for example, the teamwork learning objective was described as "students will work in groups and learn about techniques needed to create effective engineering teams." Similarly, the macroethics learning objective was explained as "students will consider the ways in which space systems impact society in positive and negative ways." This learning objective connects to ABET Student

Outcome 4, "an ability 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, 2024, p.6). Beyond ABET, instructor's personal goals for including this macroethical content were to emphasize that social and ethical issues are a valid part of aerospace engineering, and to help students learn communication strategies they can use to discuss challenging social and ethical issues in their future work.

The following macroethics lesson was presented to students two weeks into the course, with students asked to apply the same form of rightsholder analysis to the space systems they developed in their semester-long project. Macroethics content was introduced early to contextualize space systems as inextricably linked with the society they are born from, and to frame macroethical considerations as equal to other high-level systems requirements, such as mission aims and science goals. The course itself is flexible to instructor preferences and thus, though the lesson was designed to encompass an entire class period, no course material was removed to make room for macroethical content.

General Macroethics Pedagogy

The year prior, the instructor (the third author of this paper) had facilitated **small group dialogues** on macroethical topics such as planetary protection, the environmental impacts of spaceflight, commercial human spaceflight, and the military-industrial complex. The instructor presented these macroethical topics in various class meetings throughout the semester, connecting the dialogue to the space systems content being discuss that day whenever possible.

Small group discussions were selected as an educational method as they are able to be quickly formed while simultaneously prompting engagement from all participants by virtue of their limited group size. Within the class itself, the instructor first introduced the macroethical topic and connected it to the space systems content. Students were then asked to form their own small groups, not exceeding 5 students, and share their perspectives on various discussion questions presented by the instructor. Allowing students to select their own groups gave them the flexibility to join with friends with whom they may feel more comfortable discussing personal perspectives. These small group dialogues were supplemented by a larger full-class dialogue, with students sharing what their small groups discussed. The instructor facilitated this class-wide dialogue to collect broader thoughts from the class and ensure the dialogue remained harmonious.

While the instructor found these small group dialogues to be productive, he still felt they were auxiliary to the core technical work of the course—that of designing a space system. In the iteration of the course described in this paper, the instructor sought to better foster the connection between macroethics and aerospace engineering design through **rightsholder analysis and mapping**.

Rightsholder analysis is a process used in fields such as environmental policy and business management, and involves the identification and consideration of "rightsholders," individuals or entities that are affected by given decisions or practices (Vogler 2017; Weiss, 1994). These identified rightsholders are often also collaborated with and consulted to guide the creation of a final decision or outcome. Though such a process is traditionally known as "stakeholder" analysis, the instructor intentionally chose to use the terminology of "rightsholder" analysis (Rocheleau, 2024). Whereas the word "stakeholder" originally refers to someone who wagered money on a bet, the instructor wanted students to remember to consider the effect of an aerospace system on people and entities who are *not* affected financially and do not have decision-making power. Furthermore, the word "stakeholder" has colonial overtones, with how Europeans "staked" land to claim it from Indigenous peoples. The instructor instead chose to use the word "rightsholder" to ensure that no students were alienated. The terminology of "rightsholder" rather than "stakeholder" will be used within this work in accordance with this instructor decision.

The rightsholder analysis method itself was introduced to students through in-class small group activities, splitting the process into two sections: rightsholder identification and power-impact mapping. Rightsholders themselves were defined to the students as parties or entities that may be impacted by the outcome of a decision, in this case, those impacted by a particular aerospace system. Though the instructor briefly discussed the high-level goals of the rightsholder identification process, the actual learning process was self-guided, with students working in small groups to complete a worksheet, shared in Appendix B. This worksheet was adapted from a resource created by the Center for Socially-Engaged Engineering & Design at the University of Michigan. The worksheet breaks down rightsholders into four main categories: resource providers supporting the new system, benefactors and beneficiaries of the system, opposers of the system and maintainers of the status quo, and others who have limited power but could be impacted by the system. Students were challenged to identify at least one rightsholder in each category. The instructor chose to allow students to guide themselves through the learning process to strengthen their conceptual understanding and develop rightsholder identification skills through hands-on experience and small group dialogue. After small group work was completed, the class was brought back together to share out their conversations and the rightsholders they identified, with the instructor assisting the class as needed to identify examples of rightsholders in various categories.

Shortly after identifying rightsholders, students completed a power-impact map. In this activity, students considered the relative power of each rightsholder (i.e. their influence on the creation and operation of the aerospace system discussed), and how much each rightsholder would be impacted (positively and/or negatively) by the aerospace system. To visualize the differences in power and impact between various identified rightsholders, students placed the rightsholders in a quadrant graph of high-low power, and high-low impact, as seen in Figure 1. Similarly to the rightsholder identification activity, the instructor facilitated a full group dialogue of rightsholder power and impact following small group work.

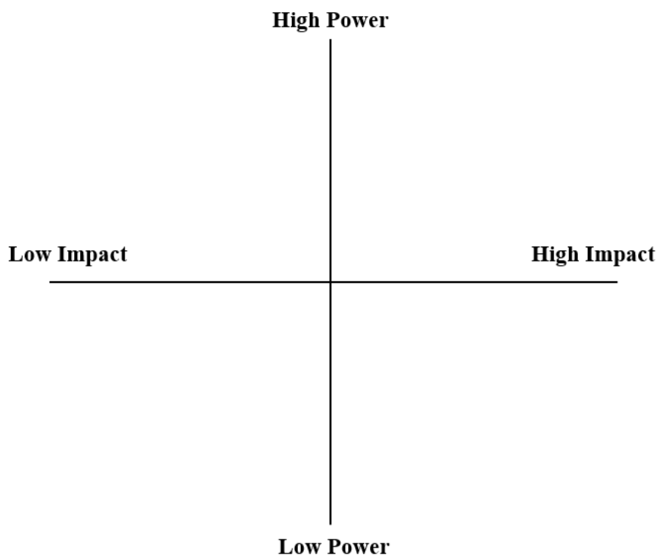

Figure 1: Blank Rightsholder Power-Impact Map

Specific Macroethics Lessons for Space Systems Design

The instructor implemented this macroethics pedagogy in two distinct activities. First, there was a one-day, in-class macroethics lesson in which students used both technical understanding and macroethical awareness to select a location of a new spaceport within the university's state. Then, later in the semester, the instructor assigned a rightsholder identification and power-impact mapping activity as a part of the students' semester-long design project. This was done to further link the macroethics content presented during the lecture to the course concept of aerospace system development, treating ethical and social considerations as equal in importance to technical considerations during the systems design process.

In-Class Lesson

The one-day, in-class macroethics lesson encompassed a full 90-minute class period. Spaceports were selected as the technical vehicle for macroethical content given their direct technical connection to the course content of space systems design, and their relevance to recent space news in Michigan. As previously mentioned, the core learning objectives of the lesson were to introduce students to the social impacts of engineering decisions, highlight the effect of personal perspectives on the decisions students make, and encourage them to begin considering broader perspectives. Class time was subdivided into multiple lecture, discussion and activity sections to guide students within this process. The remainder of this section is dedicated to detailing the specific structure of the lesson.

The lesson began with a brief lecture introducing the concepts of macroethics, the social context of engineering, and positionality. The instructor began the lesson by bringing to attention the social impact of engineering technologies, presenting examples such as GPS and satellite constellations to highlight this perspective. This introductory section also sought to motivate the concept of macroethics and its importance within the aerospace engineering field. Finally, the concept of positionality was presented and defined as the influence of time and location on personal perspectives. Students were encouraged to individually reflect on how their background and life experiences have impacted their life viewpoints. The aim of this introductory lecture portion was to ground the following activity by highlighting how students' personal viewpoints influence their opinions and decisions, and how those decisions in turn impact not only the technical engineering realm but society at large.

The lesson then transitioned to the spaceport placement activity. High-level technical material was introduced through a brief lecture defining a spaceport as a rocket launch site capable of spacecraft launch and/or landing. Kennedy Space Center in Florida, USA, was presented as an example of a spaceport. Three core technical requirements and their rationale were discussed for spaceport location selection: close proximity to the Earth's equator, availability of water to the East of the launch site, and location away from major population centers. A map of existing and proposed spaceport locations around the world was then shown to illustrate these technical requirements in action.

Following this technical overview, students formed small groups of 4-5 and selected a theoretical spaceport location within Michigan. Recent news regarding the cancellation of a spaceport project within the state was used to frame the spaceport placement activity by presenting a real-life example of such a task (Fitkin, 2024). To make their spaceport placement decision, students were encouraged to use provided demographic, infrastructure, and population maps of the state drawn from US Census Bureau data, as well as personal experiences and online resources. Once each group had decided on a location, they were asked to mark their selection on a large state map at the front of the classroom; this map was later used to spur classroom discussion. A generalized example of this map is shown in Appendix A, with circles approximating the general areas student groups chose to place their spaceport. The size of the circle corresponds to the approximate number of groups that selected that location. Of note is that all groups chose locations on the shores of the Great Lakes.

After selecting their location, each group of students was then asked to complete a rightsholder analysis worksheet, considering who or what would be impacted by spaceport development in that location. Four categories of potential rightsholders, indicated in Appendix B, were provided to encourage students to consider non-traditional rightsholders, such as the environment, within their analysis. Finally, students placed these rightsholders along an impact-power axis map and considered the amount of power and the level of impact each rightsholder experiences.

Following their small group discussions, the class was brought together to collectively work through a rightsholder analysis. A single location from the large map at the front of the classroom was selected as an example location, with the class working collectively to determine potential rightsholders and their placement on the power-impact axis map. While the data from the class has been withheld for student anonymity, a theoretical example of this map is shown in Figure 2 to demonstrate how such a rightsholder map may appear. Facilitation during this section sought to bring in new ideas and prompt students to further explain their decisions, offering alternative viewpoints and guiding class discussion to consider alternative perspectives. Rightsholders that were moved during this process of discussion are denoted with an arrow marking their movement to their final location on the map. For example, a hypothetical student originally suggested Rightsholder 2 had relatively high power and high impact. Then, a second student provided another opinion, saying that Rightsholder 2 had low impact and medium power. Finally, a third student disagreed with both, saying that Rightsholder 2 had low impact and low power. These disagreements, offered respectfully and with justification, led to productive conversations among students and the instructor.

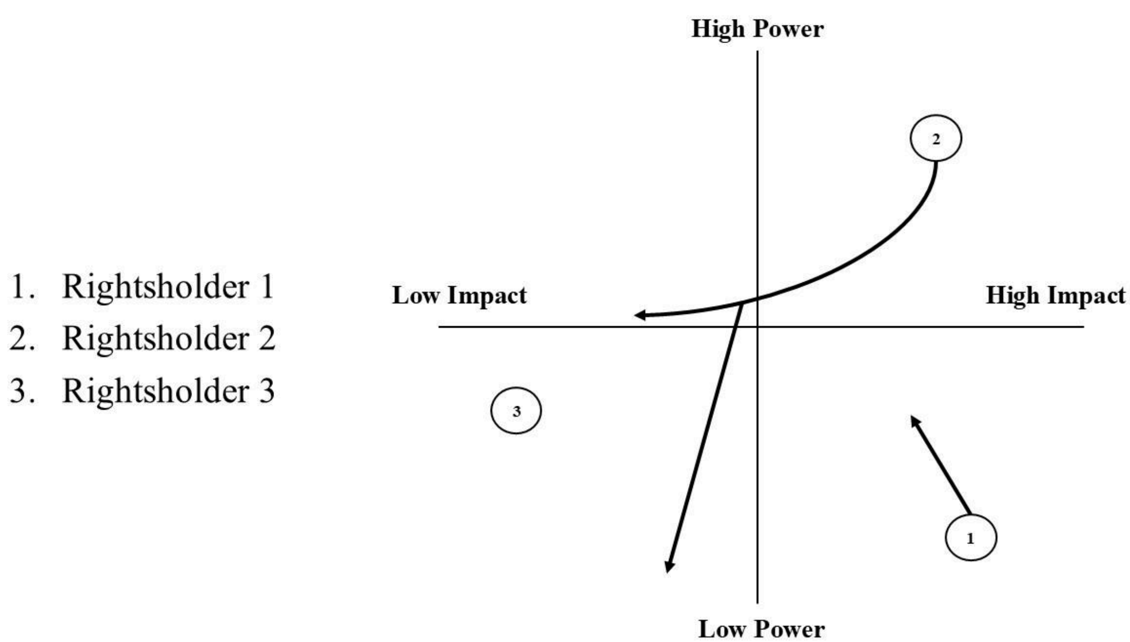

Figure 2: Example Full-Class Rightsholder Power-Impact Map

The lesson culminated in a final lecture and class-wide discussion section about dominant narratives and their impact on spaceport development efforts. The example of Kennedy Space Center in Florida, USA—a spaceport most students would likely be familiar with—was used to display how dominant narratives about land emptiness and untouched wilderness belied the lives and existence of residents and natural wildlife (Reser, 2019). Background on how Kennedy Space Center's expansion was not universally well-received during its creation, and methods used by the government to acquire land were discussed. Parallels were then drawn with the developing spaceport in Biak, Indonesia, with the region's history of military violence and intimidation negatively impacting resident perception of the spaceport (Adinda, 2023). Finally, the failure of the spaceport in the university's host state of Michigan was discussed as an example of how communities are able to actively resist unwanted technical developments (Ledy, 2023).

Course Final Report

For their capstone design project, students were tasked with developing a cislunar space system of their choice. As part of this, students applied this same rightsholder analysis process to their own proposed space systems. Each group of 10-12 students was required to come up with a list of rightsholders, place them on a power-impact map, and share their rationale for all decisions.

The primary objective of incorporating this rightsholder analysis into the project was to connect the macroethical content to students' project, thereby emphasizing the sociotechnical nature of aerospace engineering. Because no IRB-approved protocol exists that allows for the power-impact maps submitted by the student teams to be analyzed, it cannot be proven that this objective was met. However, the authors feel that this primary objective was accomplished, as students were able to identify a diverse range of rightsholders within their projects. Students identified technical rightsholders of their project, such as NASA or private spaceflight companies, but also identified some environmental, political, and social rightsholders. These included groups such as the FCC, wildlife, and indigenous groups.

Many of these "non-technical" rightsholders were likely inspired from in-class macroethical discussions. For example, Research Professor (Emeritus) of Astronomy Patrick Seitzer gave two guest lectures on satellite brightness and its effect on astronomy and on space debris regulation. This latter presentation introduced the FCC's requirement that all satellite operators develop an Orbital Debris Mitigation plan, which students were also explicitly asked to consider in their final report. Similarly, at the beginning of the semester, the instructor discussed the Navajo Nation's opposition to the placement of human remains on Astrobotic's Peregrine lunar lander. In the weeks prior to this discussion, a number of news articles were written about the Navajo's objections to what they considered to be the desecration of the moon, which holds a sacred position in their culture (Fisher, 2024). The Peregrine spacecraft ultimately launched despite these concerns, but developed a propellant leak and was deorbited in Earth's atmosphere.

Perhaps in response to this particular discussion, a number of students noted indigenous groups as rightsholders in their project rightsholder analysis.

Further work will see analysis of where students placed rightsholders on power-impact maps, the rationale provided for why rightsholders are relevant to their individual space systems, repetition of this macroethics lesson in future iterations of this course, and expansion into other relevant technical aerospace courses at more junior levels to gain a better understanding as to the efficacy of such a integrated macroethics lessons in foster student awareness of the social impact of technical engineering decisions.

Third Author's Personal Reflections as the Course Instructor

I found that incorporating these macroethics lessons into this capstone design course was easier than expected. I had originally expected students to be hesitant, or to argue that considering society and macroethics is outside the scope of the class. There were some students who did not fully participate in the in-class discussions, and one or two groups did not initially take the rightsholder analysis seriously. But, the vast majority of students enjoyed and participated seriously in the activities. We had engaging discussions about the effect of aerospace systems on society, and students did an impressive job applying the in-class rightsholder analysis to their own space system.

Logistically, it was also not too difficult to add in macroethics. For in-class small group discussions, I brought in relevant spaceflight-related current events such as the Navajo and the Peregrine mission or space environmentalism. By presenting these issues for discussion in class, I also had an excuse to dig into them myself and to learn about the current issues and debates in spaceflight.

Adding in the rightsholder analysis took a bit more work, but was still relatively smooth. The biggest change I had to make to the schedule was taking one 90-minute class period for the spaceports rightsholder analysis. After this, the rightsholder analysis was just added to their project description as one additional task to complete. Students were asked to provide a draft of this analysis in the middle of the semester, so I could give feedback. This was particularly beneficial when groups did not take the assignment seriously (e.g. by providing jokey justifications for why an entity was a rightsholder), or did not provide sufficient justifications for their thinking. But, by the end of the semester, all teams had a comprehensive rightsholder analysis.

I have continued to include this macroethical content in my space systems capstone design course, and have continued to hear positive reactions from students. I have currently incorporated the rightsholder analysis into the first deliverable students provide, which is modeled after the Formulation Agreement at the end of NASA's Pre-Phase A. The rightsholder analysis fits right into this phase, as one of the typical activities is to "identify and involve users and other stakeholders [sic]" (3.3 Project Pre-Phase A, n.d.). My goal in connecting this activity to a phase of the NASA Project Life Cycle is to further emphasize that macroethics is an integral part of the engineering process.

Initial Conclusions and Future Work

The initial data gathered from in-class observations and the instructor's reflection present an optimistic view of the feasibility of creating embedded macroethical lessons within technical aerospace coursework. Hands-on activities, such as the rightsholder analysis used within this aerospace capstone design course, allow students to actively engage with macroethical material as they would technical material, further strengthening the connection between technical and ethics content. Small group and facilitated full-class dialogues invite students to share and compare perspectives in a relatively controlled environment, allowing students to practice talking about social and ethical issues before experiencing them in the real-world. As previously mentioned, additional research will more closely analyze the rightsholder analysis and power-impact mapping activities to compare and contrast the types of identified rightsholders. This analysis will allow for a more complete understanding to be gained of how effective the lesson was in fostering student awareness of macroethical topics.

The instructor's reflection also highlights the particular value of course flexibility in creating integrated macroethics lessons and course content. The senior design course discussed was largely project focused, with time available for guest lecturers and non-technical aerospace content. In courses which may require more rigid scheduling of topics, care must be taken to determine an appropriate balance between macroethical and technical content. Through facilitation experience in this and other technical courses, the research team is working to identify a key set of skills that are particularly valuable to teach students so that they are prepared to navigate macroethical issues in their future careers. Further work will formalize these desired learning outcomes and the teaching methods that can be used to accomplish them through a conjecture mapping framework, with aims to publish these findings in the future.

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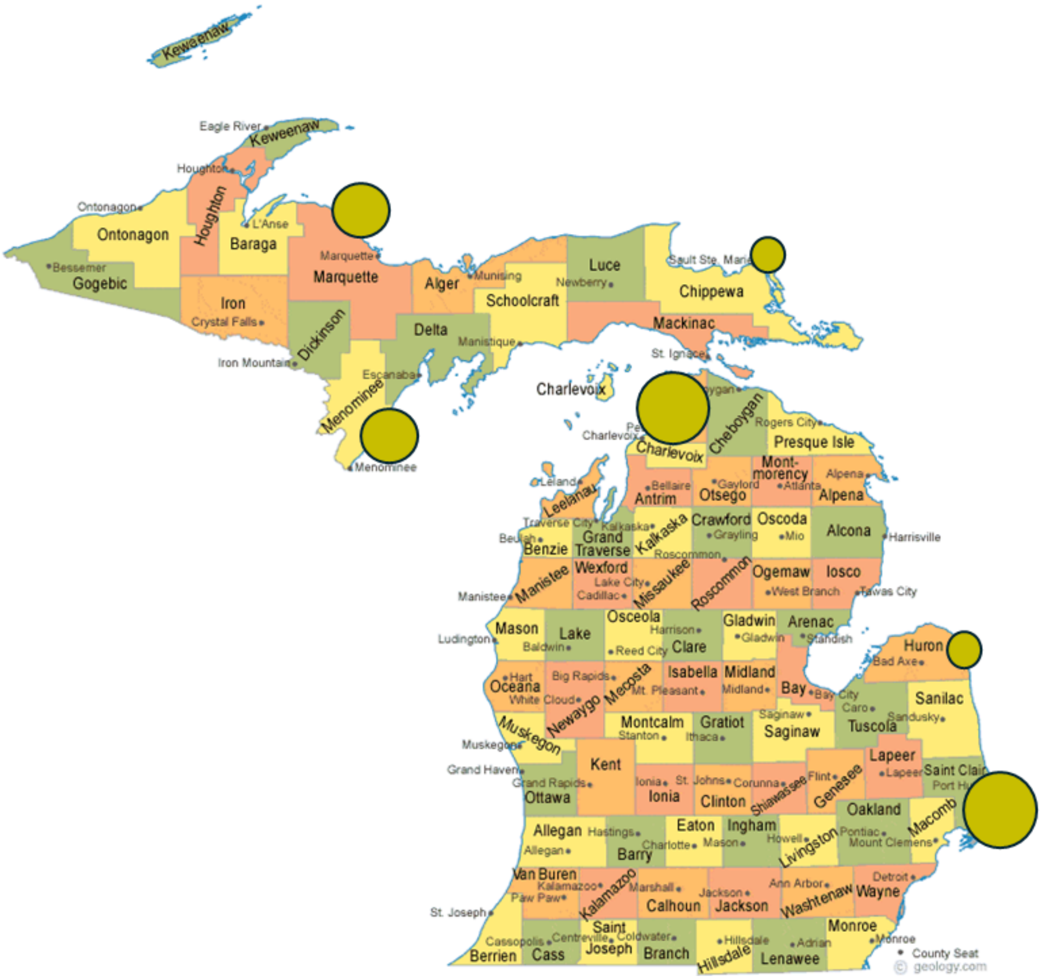
Appendix A. Example Map of Spaceport Locations Selected by Student Groups



Appendix B. Example of Rightsholder Categories

<u>Category: Resource Providers</u> *Who provides the capital (e.g., financial, human), knowledge, or resources for this spaceport?*	• • •
<u>Category: Benefactors & Beneficiaries</u> *What organizations, groups, or individuals would support the development of a spaceport in your location? How would they benefit?*	• • •
<u>Category: Opposers & Maintainers</u> *Who would oppose the development of the spaceport in your location? Who would attempt to undermine your ideal outcomes? Who would benefit from maintaining the status quo?*	• • •
<u>Category: Who & What Else</u> *All-encompassing category to consider who has limited power but could be impacted by the spaceport. Whose voice isn't typically considered? Who could influence the outcome of the facility?*	• • •