The Development of a Student Survey on Macroethics in Aerospace Engineering [Work-In-Progress]

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Abstract

This work-in-progress paper presents the development of a survey designed to understand undergraduate aerospace engineering students' views on macroethics in the field. Macroethics describes the real world ethical implications of engineering technology and the collective social responsibility of the aerospace engineering profession. As macroethics education is currently lacking in most undergraduate aerospace curricula in the United States, we are developing a survey intended to measure students' current perceptions, knowledge, and beliefs about macroethics in the field. Insight into our students' current beliefs and perceptions is imperative to develop new curricula and more generally alter the culture and direction of the aerospace engineering field from striving for apoliticalization to embracing the sociotechnical.

A mixed-methods survey was taken by 158 undergraduate aerospace engineering students at two large, research-intensive universities in the United States. This paper presents confirmatory and exploratory factor analyses of Likert-scale data to further the development of the survey. The survey items were initially designed to address two proposed research questions:

RQ1. *To what degree are students aware of the importance of macroethical issues in the field of aerospace engineering?*

RQ2. *Do aerospace engineering students feel that their undergraduate education is preparing them to address macroethical issues?*

While confirmatory factor analysis does not confirm these two survey constructs for which the survey items were designed, an exploratory factor analysis results in five factors, each highlighting a different aspect of students' perceptions of macroethical aerospace engineering education:

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

These five factors provide a new basis upon which we will generate additional survey items in the future. Through this process, we will develop a survey that can effectively measure students' beliefs and experiences in regards to the macroethical implications of the field of aerospace engineering.

Introduction

The impact of aerospace systems on society is regularly featured as part of the global news cycle. Recent topics have included protests against aerospace companies supplying equipment used in the genocide in Gaza (e.g., [1]), the objection of the Navajo Nation to planned deposition of

human remains on the Moon [2], and the increase in stratospheric pollution due to rocket launches and satellite re-entry [3]. How technology is affecting the war in Ukraine, the James Webb Space Telescope's latest findings, and SpaceX developments are other relevant examples [4]–[6]. Even viral platforms, such as TikTok and Instagram, are being used to prompt discussions about the defense industry's involvement in undergraduate education and student recruitment (e.g., [7]–[10]).

While these social impacts of aerospace engineering are discussed in the media, they are absent from many undergraduate aerospace curricula. There is little-to-no focus on *macroethics*, "the collective social responsibility of the [engineering] profession and societal decisions about technology" [11, p. 1]. Engineers face challenging questions and issues about their own work; therefore, it is critical to expose students to these issues early, emphasize the connection between technical engineering content and these issues, and give students the tools to think critically and dialogue about these issues [11]–[13].

We began creating aerospace macroethics lessons for a required sophomore aerospace course at the University of Colorado Boulder in the spring of 2021. Building off of students' feedback and overwhelmingly positive response [14], we have developed partnerships with instructors at the University of Michigan and California State University, Los Angeles to bring lessons into their aerospace engineering courses [14]–[15]. Our goal is to have these macroethics lessons build upon students' existing knowledge while exposing them to new viewpoints and challenging their own unquestioned beliefs. To accomplish this, we need to understand students' current perceptions, knowledge, and beliefs about aerospace macroethics before participating in a lesson. This includes their awareness of macroethical issues in aerospace and their level of engagement with macroethical issues in previous classes. To gain this information, we are developing a survey that contains both Likert-scale and open-ended questions. This paper presents an analysis of the Likert-scale questions that were originally designed to answer two specific research questions:

RQ1. *To what degree are students aware of the importance of macroethical issues in the field of aerospace engineering?*

RQ2. *Do aerospace engineering students feel that their undergraduate education is preparing them to address macroethical issues?*

In this paper, we describe our survey in its initial development and data collection at the University of Colorado Boulder and the University of Michigan, two large, public, selective, research-intensive universities in the United States. Usually, in the process of survey development with newly created items, researchers will perform an exploratory factor analysis followed by a confirmatory factor analysis (e.g., as in [16]), but we first present confirmatory factor analysis of a proposed two-factor structure based on our two research questions, since some of the items were taken from existing constructs (see prior work [17]). Since the proposed two-factor structure proves insufficient, we then investigate the factor structure of our survey using exploratory factor analysis, the first step in the usual survey development process. We conclude by discussing future work on the continued development of what we hope will in the future become a survey with established evidence of validity that can be administered broadly amongst aerospace engineering students.

Survey Content

Before our macroethics lessons are delivered to students, we administer an anonymous, online survey designed to understand their current perceptions, knowledge, and beliefs about aerospace macroethics. Because the survey was linked to corresponding macroethics lessons, survey items reflected the content or issues relevant to the classes (e.g., orbital debris, nuclear technology). This survey was first piloted at the University of Colorado Boulder in the spring 2022 implementation of the lessons and has undergone two revisions since. Figure 1 shows the evolution of the survey, data collection at the University of Colorado Boulder and the University of Michigan, and the major edits to the survey throughout each iteration.

The survey consists of five sections with quantitative and qualitative items that capture students' perspectives on issues of macroethics and diversity in aerospace engineering. The complete survey is provided in Appendix A. Before beginning the survey, students read consent information required by the Institutional Review Board at the University of Michigan, which oversaw the study. Continuing with the survey, students are reminded that they do not have to answer any question they do not want to. As a result, no question is required in the survey. Students are then informed that the survey addresses "macroethics" [11]. This text was added for V.2 because V.1 only used the term "ethics." Because undergraduate engineering programs in the United States typically emphasize microethics, which focuses on individual "professional" responsibility [18], we were concerned that students would focus on microethics when responding to the survey items if the concept of macroethics was not clearly defined as the focus of the survey. Furthermore, we ensured that items in the survey explicitly used the word "macroethics" instead of "ethics" whenever possible.

Likert-Scale Items

The first section of the survey (Q1 and Q2) consists of Likert-scale items addressing our two research questions. Students indicated the degree to which they agreed with each statement on a 5-point scale from strongly disagree to strongly agree. With an odd number of response options, we labeled the middle value "neither agree nor disagree" so that students could indicate a neutral response for the question. It was critical to have a neutral option, because students who respond with the neutral choice may currently believe macroethics is irrelevant to engineering. Therefore, they comprise a central target audience for the macroethical lessons.

In V.3 of the survey, there are five items addressing RQ1 and nine items addressing RQ2. Appendix A shows the source of each question–whether it was adapted from relevant existing

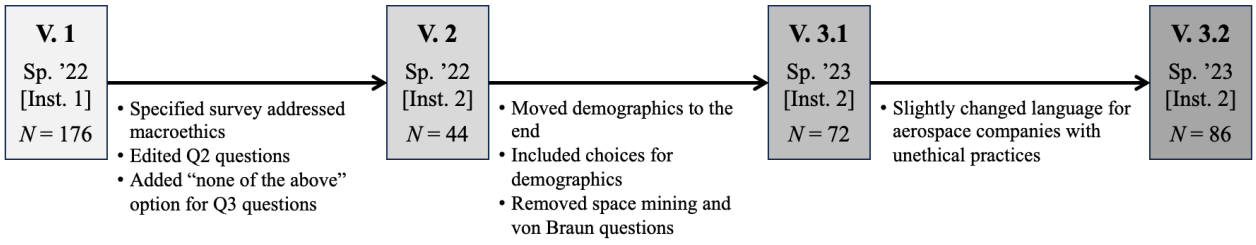

Fig. 1. Survey development.

work on students' perceptions of ethics [19] or depoliticization in engineering [20], or written by the authors. Many of these items–particularly those in Q2–were modified after the first pilot survey. Most edits were made to make the item more specific, such as changing "The ethical curriculum I have received so far will help me consider ethical issues in the aerospace industry" to "I feel prepared to consider macroethical issues in the aerospace industry today" in Q2.8. One Q1 item awas also removed from the pilot version of the survey and items Q2.4 and Q2.7 were added.

Marginalization in Aerospace Engineering

Next, the survey contains two items asking about social identities that are marginalized within the field of aerospace engineering. These items ask, "I am personally concerned about being treated differently in aerospace engineering spaces because of some aspect of my identity" (Q3.1) and "What aspects of people's identities do you believe are marginalized within aerospace engineering spaces?" (Q3.2). For both items, students are asked to "check all that apply" from a list containing: national origin, gender identity or expression, sexual orientation, disability status, veteran status, age, religion / creed, or other (with an option to describe further). These identities were adapted from the University of Colorado Boulder list of protected classes [21]. Students are also given an option of "none of the above." This was added after V.1 because a number of students skipped this question, and it was unclear if they were skipping it because they did not wish to answer or if they thought that none of these identities were marginalized. Adding a "none of the above" response option allows us to distinguish this difference. The section then concludes with an open-ended question asking, "What does diversity in aerospace engineering mean to you?" (Q3.3).

Macroethical Issues in Aerospace

The next section is designed to capture students' perspectives and attitudes about two specific macroethical issues in aerospace engineering that we frequently discuss in the lessons: satellite megaconstellations and the military-industrial complex (MIC). Both items start by providing some context and then prompts students for open-ended responses. The megaconstellations question begins with, "Satellite megaconstellations are systems that provide satellite internet through a group of orbiting satellites. SpaceX has currently launched 1,800 of their planned 4,000+ Starlink satellites, and Amazon is developing their own megaconstellation, called Project Kuiper, with 3,000+ satellites." The survey asks students if they have heard of megaconstellations, and then asks them to name up to three potential effects of a megaconstellation. They also are asked to "indicate whether [they] feel each effect is positive or negative for society." The MIC question begins with, "The major U.S. aerospace companies make most of their revenue on defense-related systems. (For example, Lockheed Martin's revenue is 96% defense, and Boeing's is 56% defense. See https://people.defensenews.com/top-100/ for more information.)" [22] and then asks students, "How do you feel about the fact that so much of the aerospace industry is involved in national defense?" Students' responses to these items are analyzed qualitatively. (The analysis is outside the scope of this paper, but please see [23]–[24] for work-in-progress analyses of students' perspectives on the MIC.) Prior versions of the survey included additional questions about other specific macroethical issues intended to gauge students' knowledge of the topics, but these items were removed in V.3 due to survey

length and students' responses that seemed to poorly relate to the scope of our research questions.

This section of the survey concludes by asking about classes in which students have previously learned about macroethics in aerospace engineering and by asking, "What does it mean to be an ethical aerospace engineer?" (Q4.5). This final question comes from Gupta's [25] macroethics activity for an engineering design course and was included to further understand students' perceptions of "ethics" as micro-, macro-, or both.

Demographics

Finally, the survey concludes by asking students about their demographics. Originally, the demographics items all allowed students to self-describe their identity along multiple dimensions (e.g. race/ethnicity, gender, and sexuality). However, to ease the data analysis, this has since been changed to present students with multiple options and allow them to choose one or self-describe. Students are given seven options for race/ethnicity and three options for gender. Instead of asking to self-describe or choose a sexual identity, students are asked, "Do you consider yourself to have a LGBTQIA+ identity?" This question is worded this way because there were multiple instances in the first two pilot surveys where students would write the same word (e.g., "male") for both their self-described gender and sexual identities. It is unclear whether these students were indicating they were attracted to the same gender or if they misunderstood what we meant by "sexual identity."

The survey also asks if the student is "an active member or veteran of the U.S. Armed Forces, Reserves, or National Guard" and if they are a U.S. Citizen. These identities are particularly influential in aerospace engineering because of the connections between the field and national defense. It would not be surprising if military service were to, for example, influence students' perceptions on the MIC. Furthermore, many non-U.S. Citizens have difficulty securing a job in the aerospace industry because of International Traffic in Arms Regulations restrictions [26].

The demographic items serve multiple purposes in our survey and in our research. First, these data permit future analyses investigating if students' responses differed depending on whether or not they were marginalized in aerospace engineering based on some aspect of their identity. Furthermore, whether or not these analyses are being conducted, it still is important to be transparent about subjects' demographics in education research to avoid generalizations to populations outside those that are the subjects of the research. Failing to do so can lead to incorrect assumptions about the subjects [27]. In the first two pilot implementations, the demographics items were placed at the beginning of the survey. However, existing research suggests that demographics items should be placed at the end of surveys due to their potential to cause stereotype threat for marginalized students [28]. For this reason, the demographics items were moved to be placed at the end of the survey.

Survey Administration

In Spring 2023, the survey was administered to aerospace engineering undergraduate students at the University of Colorado Boulder and the University of Michigan. Students were surveyed in two classes where we were implementing macroethics lessons–a sophomore aerospace vehicle

design course at the University of Colorado Boulder and a senior space system design course at the University of Michigan. Prior to the planned macroethics lesson(s), students enrolled in each course were asked to take the survey online. A total of 158 students took the survey, 86 from the University of Colorado Boulder and 72 from the University of Michigan. This sample size meets recommendations of at least 100 responses to be used for factor analysis [29]–[30].

Confirmatory Factor Analysis

Methods

We first performed a confirmatory factor analysis (CFA) in Stata hoping to verify the appropriateness of our constructed survey to directly answer our two research questions (as proposed in [17]). It was proposed that the five items written to address RQ1 comprised a single latent factor and the nine items written to address RQ2 comprised a second latent factor. Thus, we proposed a two-factor structure: one describing students' awareness of macroethical issues in aerospace engineering and another describing the degree to which students believe the aerospace engineering curriculum is preparing them to address macroethical issues in their future careers. The items are shown in Appendix A in Sections 1 and 2 of the survey. Some survey items were reverse-coded, as noted in Appendix A, which means that their inverse maps conceptually to the remainder of the items. In other words, "strongly agree" for typical items maps to "strongly disagree" for reverse-coded items.

First, reasonable skewness and kurtosis of each item were verified to justify the use of the Maximum Likelihood estimation (ML) method for missing values, which is recommended by Fabrigar et al., particularly for ease of computation of goodness-of-fit [31]. Then, confirmatory factor analysis was performed and the standardized loadings were determined. Goodness of fit was also measured.

Results and Discussion

The maximum absolute value of the skewness and kurtosis of the 14 items was 1.38 and 5.20, respectively (both for item Q1.3). This is within the acceptable range for the use of the ML method [31]–[32]. The confirmatory factor analysis model results are shown in the path diagram in Figure 2. The standardized loading of each item is labeled on the arrow from its latent factor, and the variances for each factor and item are provided inside the ovals and boxes, respectively. The error terms are also provided in the circles. Each latent factor had only two items, or measurement variables, with factor loadings about the standard cutoff of .60, which are shown in bold in Figure 2. Hair et al. suggest that factor loadings should ideally be above .70 [33]. None of our items loaded above .70, however, and one had a negative factor loading, meaning that it was inversely related to the conceptual factor. Following standard procedure using the results of CFA, we would remove items that do not load to the cutoff value, but doing so would result in no usable factors if we follow the usual protocol requiring at least three high-loading items per factor [34]. Thus, our CFA results in no usable factors presuming the proposed factor structure.

Goodness-of-fit to the proposed factor structure was also tested using the indices shown in Table I. We note that, since the chi-squared p-value is very sensitive to sample size [35]–[36], the inadequacy of the result is not as telling as that of the other indices. The substandard results of all

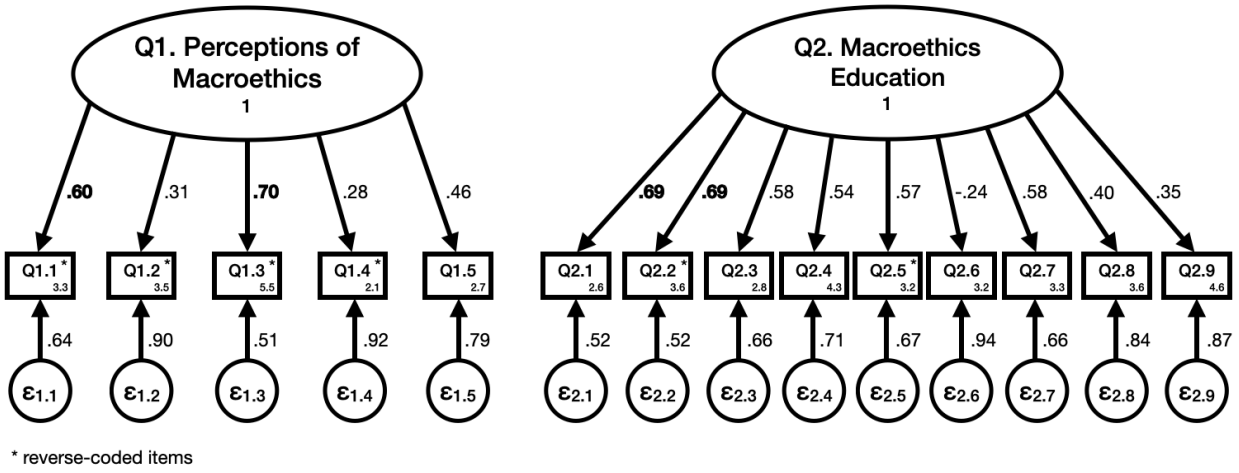

Fig. 2. Path diagram resulting from confirmatory factor analysis of the proposed two-factor structure.

of the goodness-of-fit indices provide additional evidence of the poor fit of the proposed factor structure.

This CFA statistically shows the poor fit seen in [17], in which the inconsistency of results across the two factors was observed. Therefore, our survey does not directly answer our two research questions as was hoped, with Section Q1 and Q2 addressing RQ1 and RQ2 respectively.

Exploratory Factor Analysis

Given the result of the CFA described in the previous section, we instead explore the factor structure of our survey using exploratory factor analysis (EFA). In this way, we hope to make sense of how a rearrangement of some of our existing survey items can help us build toward the development of a future survey that provides insight into our proposed research questions.

Methods

Again employing the ML method for estimating missing values, which is valid since the skewness and kurtosis of each item render the assumption of normal distribution reasonable [31]–[32], we ran an EFA on the same set of 158 responses. The analysis resulted in three Heywood Cases, which exhibit negative variance of uniqueness [37]. We therefore removed each of the corresponding items from the analysis and re-ran the EFA, which produced another Heywood case. This process was iterated until a satisfactory model was obtained.

Results and Discussion

The resulting factor loadings are shown in Table II. All loadings above 0.1 are included in the table, with loadings above the cutoff value of .32 [29] indicated with bold font. As can be seen in Table II, while cross-loading across multiple factors does occur, no items cross-loaded with

TABLE I
GOODNESS-OF-FIT INDICES FOR THE PROPOSED TWO-FACTOR STRUCTURE

Index	*Standard*	*Result*
Chi-squared p-value	$p > .05$	$p < .005$
RMSEA	$0 < RMSEA < .08$	.092
90% CI of RMSEA	0 < 90% CI of RMSEA < .08	.074 and .110
CFI	$CFI > .85$	.759
TLI	$TLI > .9$	.711
SRMR	$SMSR < .08$	.093

TABLE II
RESULTANT LOADINGS FROM EXPLORATORY FACTOR ANALYSIS

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

loadings higher than .32. Thus, no items were removed on the basis of cross-loading. Five factors emerged from the final model, each containing two or fewer items with loadings above .32.

Items Q2.1 and Q2.3 loaded to Factor 1, indicating that there exists some underlying concept in common for these two items. The items are “In my engineering coursework thus far there has been a substantial emphasis on macroethics in aerospace engineering” and “In my classes, I have often had the opportunity to initiate discussions regarding macroethical issues.” A conceptual connection between these two items seems logical, because emphasizing a certain topic can be done pedagogically in many ways, and one method is to spend time in discussion. It seems reasonable that students may notice more emphasis on macroethics if there are more opportunities for students to initiate discussions about macroethics.

Items Q1.1 and Q2.6, which are “Aerospace engineering is a ‘technical’ space where ‘social’ or ‘political’ issues such as inequality are irrelevant to engineers’ work” (reverse-coded) and “I wish there was more emphasis on macroethics in aerospace engineering in my engineering coursework” loaded to a second factor. The EFA showed that students who agreed that social issues are relevant to the field of aerospace engineering also want more exposure to macroethics in their engineering coursework. It does seem logical that these items loaded to the same factor, despite the fact that they were originally intended to measure two different concepts as defined in RQ1 and RQ2. As macroethics has been lacking in engineering education in the United States [11], [12], [17], [38], it seems reasonable that students who recognize the importance of the relationship between engineering and society would want to see more macroethics content included in the curriculum.

The third factor that emerged within our EFA demonstrated a conceptual relationship between questions Q2.5 and Q2.7, which state “My professors have rarely expressed personal concern over macroethical issues in aerospace engineering” (reverse-coded) and “The ethical curriculum I have received so far has prepared me to engage in respectful and challenging dialogue with my peers.” While these questions have weaker loadings than items in other factors, a conceptual link may exist due to student perceptions of how faculty aid in engaging in dialogue with student

peers. Students who feel that their professors are uninterested in ethical issues pertaining to the aerospace industry may in turn feel unprepared to engage in difficult, but necessary, ethical conversations with peers due to the lack of in-class support. This suggests that how faculty choose to engage, or disengage, with macroethics dilemmas in engineering could directly impact students' ability to engage in dialogue about these same ethical issues [39].

A fourth factor suggests conceptual linkage between items Q1.4 and Q1.5, which state that "Technology can't be good or bad in itself. What matters is how people choose to use the technology." (reverse-coded) and "I know of aerospace companies that I wouldn't consider working for because their practices are unethical." The former item directly addresses the concept of technological determinism, in which emerging technology is viewed as a driving force within culture that often influences the direction of history [40]. When students feel that emerging technology is politically neutral, a level of moral detachment occurs. This results in a "disengagement" of engineers from the social impacts of their work [41]–[42]. Engineers who adopt this way of thinking often offload the responsibility of how technology should be used onto leaders and policymakers, which often leads to misinformed and ill-equipped decision making. The relationship between these items implies that if an engineer feels technology can be neutral, they are able to develop a certain amount of disengagement when it comes to the implications of their work. This suggests that these students may be more willing to work with a company that engages in unethical practices. However, if a student feels that technology cannot be neutral, they may be more willing to recognize the unethical practices of aerospace companies, which can in turn influence that engineer's career trajectory as they purposely avoid employment with these particular companies.

The results of the EFA (in conjunction with those of the CFA previously discussed) suggest that our Likert-scale items map to five separate factors, rather than the two originally proposed based on our research questions. However, we do not have a sufficient quantity of items to quantitatively measure the five factors, given the standard of at least three items per factor [34]. In fact, the fifth factor only has a single item that exhibited sufficiently high loading ("It is easy to be an ethical engineer in the aerospace industry." (reverse-coded)). Thus, it is necessary to develop additional survey items that map using EFA to these five factors before the constructs can be statistically confirmed with a subsequent CFA.

Conclusions and Future Work

The absence of macroethics education from aerospace engineering undergraduate curricula leaves students ill-prepared to recognize and address challenging ethical questions they will encounter in their future careers. There is a pressing need to put aerospace engineering in its social context and discuss the collective responsibility of the field. We are addressing this need by implementing macroethics lessons that inform students about macroethical issues in aerospace engineering and allow them to develop their critical thinking skills. The development of a survey with evidence of validity will help us ensure that the lessons build on students' current understanding of these issues and expose them to marginalized viewpoints.

This paper has described our work toward the development of a survey instrument to measure students' awareness of the importance of macroethics in aerospace engineering and their perceptions of macroethics education. The confirmatory factor analysis demonstrated that our

initial proposition of a two-factor structure directly addressing our two research questions did not hold. In light of the results of the exploratory factor analysis, the development of the instrument will continue with the creation of additional survey items informed by the conceptual bases linking the five factors:

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

After we administer an updated version of the survey with additional items, we will perform exploratory and confirmatory factor analyses and goodness-of-fit tests. Once our instrument is demonstrating sufficient evidence of validity, we can begin to analyze the results by comparing responses across demographic populations. The quantitative results will also be triangulated with the qualitative results from the survey, as this mixed-methods approach produces a rich dataset that is well posed to advance our knowledge of students' perceptions of macroethics.

Macroethics education is imperative to an engineering education that builds students' ability to critically analyze the applications and impacts of aerospace technology. While aerospace engineering programs are currently sorely lacking in this area, our design-based research works to both understand students' current awareness as well as provide educational intervention supports students' preparedness to use their engineering knowledge in purposefully liberative ways [43]. With knowledge of macroethics, students will be better equipped to make important decisions about their future careers in aerospace engineering such that they can intentionally and collaboratively build a more just and equitable world.

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Appendix A: Survey

Plain text is text that was presented on the survey, whereas italicized text is explanation for the reader.

The scale for items that are reverse-coded was flipped when these items were put into the Confirmatory and Exploratory Factor Analyses.

As you complete the survey, please remember that you do not have to answer any question you do not want to answer.

This survey asks questions about macroethics. Macroethics applies to the collective, social responsibility of the engineering profession and societal decisions about technology.

Section 1

Please indicate how much you agree with the following statements.

For each item below, choose one of: Strongly disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree

Q1.1. Aerospace engineering is a "technical" space where "social" or "political" issues such as inequality are irrelevant to engineers' work. (*Reverse-coded. Adapted from Cech's definition of depoliticization [20].*)

Q1.2. It is easy to be an ethical engineer in the aerospace industry. (*Reverse-coded. Written by the authors*)

Q1.3. Ethical issues do not pertain to new aerospace technologies or systems. (*Reverse-coded. Adapted from Jimerson et al. [19].*)

Q1.4. Technology can't be good or bad in itself. What matters is how people choose to use the technology. (*Reverse-coded. Written by the authors.*)

Q1.5. I know of aerospace companies that I wouldn't consider working for because their practices are unethical. (*Written by the authors.*)

If the response is Agree or Strongly Agree, a follow-up question is asked: What are the practices of aerospace companies that you consider to be unethical?

Section 2

Please indicate how much you agree with the following statements.

For each item below, choose one of: Strongly disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree

Q2.1. In my engineering coursework thus far there has been a substantial emphasis on macroethics in aerospace engineering. (*Adapted from Jimerson et al. [19].*)

Q2.2. As a whole, my professors have avoided discussions of macroethical issues. (*Reverse-coded. Adapted from Jimerson et al. [19].*)

Q2.3. In my classes, I have often had the opportunity to initiate discussions regarding macroethical issues. (*Adapted from Jimerson et al. [19].*)

Q2.4. Undergraduate engineering students are able to learn about macroethics. (*Written by the authors.*)

Q2.5. My professors have rarely expressed personal concern over macroethical issues in aerospace engineering. (*Reverse-coded. Adapted from Jimerson et al. [19].*)

Q2.6. I wish there was more emphasis on macroethics in aerospace engineering in my engineering coursework. (*Adapted from Jimerson et al. [19].*)

Q2.7. The ethical curriculum I have received so far has prepared me to engage in respectful and challenging dialogue with my peers. (*Written by the authors.*)

Q2.8. I feel prepared to consider macroethical issues in the aerospace industry today. (*Written by the authors.*)

Q2.9. My aerospace professors have the knowledge necessary to teach me about macroethics in our classes. (*Written by the authors.*)

Section 3

For each item below, check all that apply: Race/ethnicity, National original, Gender identity or expression, Sexual orientation, Disability status, Veteran status, Age, Religion/creed, Other (please specify below), None of the above

Q3.1. I am personally concerned about being treated differently in aerospace engineering spaces because of some aspect of my identity.

Q3.2. What aspects of people's identities do you believe are marginalized within aerospace engineering spaces?

For the item below, provide an open-ended response

Q3.3. What does diversity in aerospace engineering mean to you?

Section 4

Subsection 4.1. Satellite megaconstellations are systems that provide satellite internet through a group of orbiting satellites. SpaceX has currently launched 1,800 of their planned 4,000+ Starlink satellites, and Amazon is developing their own megaconstellation, called Project Kuiper, with 3,000+ satellites.

For the item below, choose one of: Yes, No

Q4.1. Have you heard of satellite megaconstellations before?

For the item below, provide an open-ended response

Q4.2. Name potential effects of a satellite megaconstellation and indicate whether you feel each effect is positive or negative for society. (Up to 3)

Subsection 4.2. The major U.S. aerospace companies make most of their revenue on defense-related systems. (For example, Lockheed Martin's revenue is 96% defense, and Boeing's is 56% defense. See https://people.defensenews.com/top-100/ for more information).

For each item below, provide an open-ended response

Q4.3. How do you feel about the fact that so much of the aerospace industry is involved in national defense?

Subsection 4.3.

Q4.4. In what courses at [university] have you learned about macroethics in engineering?

Q4.5. What does it mean to be an ethical aerospace engineer?

Section 5

How would you describe your:

For each item below, check all that apply: American Indian, Native American, or Alaskan Native; Asian or Asian-American; Black or African-American; Hawaiian Native or Pacific Islander; Hispanic, Latinx, or Chicanx; Middle Eastern, Arab, or Arab-American; White, Caucasian, or European-American; Self-describe; Prefer not to answer

Q5.1. Race / ethnicity?

For the item below, choose one of: Genderqueer / Non-binary, Woman, Man, Self-describe, Prefer not to answer

Q5.2. Current gender identity?

For each item below, choose one of: Yes, No, Prefer to self-describe, Prefer not to answer

Q5.3. Do you consider yourself to have a LGBTQIA+ identity?

Q5.4. Do you identify as an active member or veteran of the U.S. Armed Forces, Reserves, or National Guard?

Q5.5. Are you a U.S. Citizen?

Q5.6. Are you 25 years of age or older?

Q5.7. Do you consider yourself a first-generation college student?

Q5.8. Do you consider yourself to have any disabilities or learning difficulties?

For the item below, choose an integer 1-12 on a slider

Q5.9. Including this semester, how many semesters have you been in college (at [university] or elsewhere)? (If you have been in college more than 12 semesters, select "12" on the slider

References

[1] P. O'Gorman and E. Gawne, "Gaza protesters block BAE Systems aerospace factory in Lancashire," BBC News, Dec. 07, 2023. Accessed: Feb. 01, 2024. [Online]. Available: https://www.bbc.com/news/uk-england-lancashire-67650061.

[2] J. Hernandez, "Navajo Nation objects to a plan to send human remains to the moon," National Public Radio: Space, Jan. 08, 2024. Accessed: Feb. 01, 2024. [Online]. Available: https://www.npr.org/2024/01/08/1223377817/navajo-moon-human-remains.

[3] S. Hall, "The New Space Race Is Causing New Pollution Problems," The New York Times, Jan. 09, 2024. Accessed: Feb. 01, 2024. [Online]. Available: https://www.nytimes.com/2024/01/09/science/rocket-pollution-spacex-satellites.html.

[4] P. Politiyuk, T. Balmfourth, and T. Heritage, "Ukraine receives first delivery of NASAMS air defence systems," Reuters, Nov. 07, 2022. Accessed: May 31, 2023. [Online]. Available: https://www.reuters.com/business/aerospace-defense/ukraine-receives-first-delivery-nasams-air-defence-systems-minister-2022-11-07/.

[5] V. Gill, "Nasa's James Webb telescope reveals millions of galaxies," BBC News, Jul. 22, 2022. Accessed: May 31, 2023. [Online]. Available: https://www.bbc.com/news/science-environment-62259492.

[6] A. Therrien, “SpaceX Starship live: SpaceX Starship finally launches but blows up after take-off,” BBC News, Apr. 20, 2023. Accessed: May 31, 2023. [Online]. Available: https://www.bbc.co.uk/news/live/science-environment-65330571.

[7] [@kellyintherealworld] kelly in the real world, “the defense contractor salaries are high for a reason babes #college #study #engineering #militaryindustrialcomplex,” TikTok, Sep. 13, 2022. Accessed: Feb. 01, 2024. [Online]. Available: https://www.tiktok.com/@kellyintherealworld/video/7142990574835010858.

[8] [@avgeektok] AvGeekTok, “And the military industrial complex loves them 😁#militaryindustrialcomplex #engineeringmajorsbelike #collegemajorslander #engineeringstudent #aerospaceengineering #aviationmemes #military #fyp,” TikTok, Feb. 14, 2023. Accessed: Feb. 01, 2024. [Online]. Available: https://www.tiktok.com/@avgeektok/video/7200156718636993834.

[9] [@avgeektok] AvGeekTok, “The innocent 5’4 130lb engineer major: 🤩#militaryindustrialcomplex #engineeringmajorsbelike #collegemajorslander #engineeringstudent #aerospaceengineering #engineeringjobs #rahhhh #militarymemes #lockheedmartin #fyp,” TikTok, Feb. 18, 2023. Accessed: Feb. 01, 2024. [Online]. Available: https://www.tiktok.com/@avgeektok/video/7200156718636993834.

[10] [@calliecarlsen] Callie, “#greenscreen a tad bit hypocritical #cuboulder #engineering #colorado #boulder #lockheedmartin #womeninstem #college #cu,” TikTok, Nov. 13, 2023. Accessed: Feb. 01, 2024. [Online]. Available: https://www.tiktok.com/@calliecarlsen/video/7301148560077098271.

[11] 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.

[12] W. A. Wulf, “Keynote Address” in Emerging Technologies and Ethical Issues in Engineering. Washington, D.C.: National Academies Press, 2004. doi: 10.17226/11083.

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

[14] A. Benham et al., “Developing and Implementing an Aerospace Macroethics Lesson in a Required Sophomore Course,” in 2021 IEEE Frontiers in Education Conference (FIE), Lincoln, NE, USA: IEEE, Oct. 2021, pp. 1–9. doi: 10.1109/FIE49875.2021.9637172.

[15] M. Ennis, E. Strehl, A. W. Johnson, C. L. Bowen, and O. Jia-Richards, “Work in Progress: Implementing an Orbital Debris Macroethics Lesson in a Junior-Level Spacecraft Dynamics Course,” in 2023 ASEE Annual Conference & Exposition Proceedings, Baltimore, MD: ASEE Conferences, 2023.

[16] D. Verdín, J. M. Smith, and J. C. Lucena, “Recognizing the funds of knowledge of first-generation college students in engineering: An instrument development,” *J Eng Educ*, vol. 110, no. 3, pp. 671–699, Jul. 2021, doi: 10.1002/jee.20410.

[17] A. Benham, R. Fotherby, A. W. Johnson, and C. L. Bowen, “Student Perspectives of Aerospace Engineering Macroethics Issues and Education,” in 2022 IEEE Frontiers in

Education Conference (FIE), Uppsala, Sweden: IEEE, Oct. 2022, pp. 1–5. doi: 10.1109/FIE56618.2022.9962654.

[18] J. R. Herkert, "Engineering ethics education in the USA: Content, pedagogy and curriculum," Eur. J. Eng. Educ., vol. 25, no. 4, pp. 303–313, Dec. 2000, doi: 10.1080/03043790050200340.

[19] B. Jimerson, E. Park, V. Lohani, and S. Culver, "Enhancing Engineering Ethics Curriculum by Analyzing Students' Perception," in 2013 ASEE Annual Conference & Exposition Proceedings, Atlanta, Georgia: ASEE Conferences, Jun. 2013. doi: 10.18260/1-2--19544.

[20] E. A. Cech, "The (Mis)Framing of Social Justice: Why Ideologies of Depoliticization and Meritocracy Hinder Engineers' Ability to Think About Social Injustices," in Engineering Education for Social Justice, J. Lucena, Ed., in Philosophy of Engineering and Technology, vol. 10. Dordrecht: Springer Netherlands, 2013, pp. 67–84. doi: 10.1007/978-94-007-6350-0_4.

[21] "Protected Class Definitions," Don't Ignore It, Feb. 02, 2017. https://www.colorado.edu/dontignoreit/what-report/discrimination-harassment/protected-class-definitions (accessed May 31, 2023).

[22] "Top 100 | Defense News, News about defense programs, business, and technology," Defense News, 2022. https://people.defensenews.com/top-100/ (accessed May 31, 2023).

[23] E. A. Strehl, M. Ennis, A. W. Johnson, and C. L. Bowen, "Work in Progress: Undergraduate Student Perceptions of Macroethical Issues in Aerospace Engineering," in 2023 ASEE Annual Conference & Exposition Proceedings, Baltimore, MD: ASEE Conferences, Jun. 2023. doi: 10.18260/1-2--44383.

[24] E. A. Strehl, S. Olson, C. L. Bowen, & A. W. Johnson, "Work in Progress: Navigating Undergraduates' Perspectives on Macroethical Dilemmas in Aerospace Engineering," in 2024 ASEE Annual Conference & Exposition Proceedings, Portland, OR: ASEE Conferences, Jun. 2024.

[25] A. Gupta, "A Practitioner Account of Integrating Macro-ethics Discussion in an Engineering Design Class," in 2017 ASEE Annual Conference & Exposition Proceedings, Columbus, Ohio: ASEE Conferences, Jun. 2017, p. 27498. doi: 10.18260/1-2--27498.

[26] K. L. B. Cook, "The ITAR and you - what you need to know about the International Traffic in Arms Regulations," in 2010 IEEE Aerospace Conference, Big Sky, MT, USA: IEEE, Mar. 2010, pp. 1–12. doi: 10.1109/AERO.2010.5446878.

[27] A. L. Pawley, "Shifting the 'Default': The Case for Making Diversity the Expected Condition for Engineering Education and Making Whiteness and Maleness Visible," J. Eng. Educ., vol. 106, no. 4, pp. 531–533, 2017, doi: 10.1002/jee.20181.

[28] K. Danaher and C. S. Crandall, "Stereotype Threat in Applied Settings Re-Examined," J. Appl. Soc. Psychol., vol. 38, no. 6, pp. 1639–1655, Jun. 2008, doi: 10.1111/j.1559-1816.2008.00362.x.

[29] B. G. Tabachnick and L. S. Fidell, Using multivariate statistics, 6th ed. Boston: Pearson Education, 2013.

[30] R. L. Gorsuch, "Exploratory Factor Analysis: Its Role in Item Analysis," J. Pers. Assess., vol. 68, no. 3, pp. 532–560, Jun. 1997, doi: 10.1207/s15327752jpa6803_5.

[31] L. R. Fabrigar, D. T. Wegener, R. C. MacCallum, and E. J. Strahan, "Evaluating the use of exploratory factor analysis in psychological research.," Psychol. Methods, vol. 4, no. 3, pp. 272–299, Sep. 1999, doi: 10.1037/1082-989X.4.3.272.

[32] P. J. Curran, S. G. West, and J. F. Finch, "The robustness of test statistics to nonnormality and specification error in confirmatory factor analysis.," Psychol. Methods, vol. 1, no. 1, pp. 16–29, Mar. 1996, doi: 10.1037/1082-989X.1.1.16.

[33] J. F. Hair, Ed., Multivariate data analysis, 7th ed. Upper Saddle River, NJ: Prentice Hall, 2010.

[34] W. F. Velicer and J. L. Fava, "Affects of variable and subject sampling on factor pattern recovery.," Psychol. Methods, vol. 3, no. 2, pp. 231–251, Jun. 1998, doi: 10.1037/1082-989X.3.2.231.

[35] T. A. Brown, Confirmatory factor analysis for applied research, Second edition. in Methodology in the social sciences. New York ; London: The Guilford Press, 2015.

[36] R. B. Kline, Principles and practice of structural equation modeling, Fourth edition. in Methodology in the social sciences. New York: The Guilford Press, 2016.

[37] A. W. Cooperman and N. G. Waller, "Heywood you go away! Examining causes, effects, and treatments for Heywood cases in exploratory factor analysis.," Psychol. Methods, vol. 27, no. 2, pp. 156–176, Apr. 2022, doi: 10.1037/met0000384.

[38] 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), Indianapolis, IN: IEEE, Oct. 2017. doi: 10.1109/FIE.2017.8190445.

[39] M. Polmear, A. Bielefeldt, D. Knight, C. Swan, and N. Canney, "Faculty Perceptions of Challenges to Educating Engineering and Computing Students About Ethics and Societal Impacts," in 2018 ASEE Annual Conference & Exposition Proceedings, Salt Lake City, Utah: ASEE Conferences, Jun. 2018. doi: 10.18260/1-2--30510.

[40] R. Williams and E. Williams, Television: technology and cultural form. in Routledge classics. London ; New York: Routledge, 2003.

[41] E. A. Cech, "Culture of Disengagement in Engineering Education?," *Science, Technology, & Human Values*, vol. 39, no. 1, pp. 42–72, Jan. 2014, doi: 10.1177/0162243913504305.

[42] D. M. Riley and Y. Lambrinidou, "Canons against Cannons? Social Justice and the Engineering Ethics Imaginary Social Justice and the Engineering Ethics," in 2015 ASEE Annual Conference & Exposition Proceedings, Seattle, Washington: ASEE Conferences, Jun. 2015. doi: 10.18260/p.23661.

[43] P. Freire, Pedagogy of the Oppressed. New York, NY: Bloomsbury Academic, 2000.