Characterizing Student Identities in Engineering: Attitudinal Profiles of Engineering Majors

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Characteristics of Student Identities in Engineering

This paper presents results of work completed to date on our project, Intersectionality of Non-normative Identities in the Cultures of Engineering (InIce) (NSF 1428689/1428523). The overarching focus of this work is on how students who hold non-normative identities position themselves, grow through their education, and navigate the cultures of engineering they experience in college. Our goal is to investigate ways to engage students with non-normative identities to become more active and life-long participants in engineering disciplines. Our work is proceeding in three phases: 1) Identify, through a quantitative instrument, the normative and non-normative attitudinal profiles of students in engineering; 2) Characterize students' normative and non-normative identities through in-depth interviews and analysis of differences between students with normative and non-normative identities in engineering; and 3) Drawing from our findings, develop a workshop and set of courses to incorporate diversity topics into engineering programs to enhance the culture of engineering to be more responsive towards, and inclusive of, a diverse range of student identities.

In this paper, we report on the completion of our first phase using quantitative measures to characterize student groups with normative and non-normative identities in engineering. Our definitions of normative and non-normative for this project are developed through Topological Data Analysis (TDA) of multi-institution survey data (n = 2916). TDA allows identification of groups without imposing *a priori* hypotheses on how the attitudes of students may group together (nor how attitudes may distinguish between demographic groups). This approach allows the underlying structure of the data to emerge rather than imposing pre-defined definitions of normative attitudes or identities. Our TDA results revealed one main group (the "normative" group), seven groups that were related but distinctly different from the normative group ("non-normative groups") and the rest of the students who were not closely related to these groups or each other ("disparate group"). We have compiled a summary of the most salient attitudinal constructs in terms of characterizing and distinguishing between groups, including: motivation (value, goal orientation, future time perspective), engineering and physics identities (performance/competence and recognition beliefs), personality (neuroticism, extraversion, belongingness) and grit (consistency of interest).

In the next phase of our study, we are conducting a series of qualitative, longitudinal interviews with students selected from normative and non-normative groups to understand how they navigate their engineering experiences and define their educational trajectories over the first two years of college. This data is being deductively analyzed based on our existing identity and intersectionality frameworks, as well as inductively coded for emerging themes on how students feel belongingness within engineering culture.

This project seeks to move traditional demographic data beyond socially constructed perceptions of others and allows for the representation of student diversity from the perspective of each participant. This increasingly accurate reflection of diversity provides novel insight into the experiences of students who might otherwise be ignored or unjustifiably lumped in with other students who share some demographic indicator and how residing at the intersection of multiple measures of diversity influences students' experiences in engineering culture.

The Landscape of Diversity in Engineering

The lack of diversity in engineering is a persistent issue that hinders the development of comprehensive solutions to engineering problems, limits the quality of the engineering field, and restricts accessibility to the social and economic capital available to those in engineering careers[1]. Few inroads into engineering exist beyond the first year in college[2]. Thus, greater diversity in engineering requires more effective recruitment of a greater breadth of students into engineering programs at the outset as well as more effectively retaining these students in college. The transition to college is a critical point at which students must be empowered to choose engineering. If this opportunity for transitioning into engineering is lost for many students, the engineering community will largely remain as it is today.

While attitudes toward engineering and science careers may begin to form at the middle school level, high school science and math experiences have a large effect on students' later choice of engineering as a career[3,4]. It is important to note that students who leave engineering often do not do so because they cannot do the work, are inadequately prepared, or lack the desire to work hard. One of the most common reasons students give for switching is a feeling of not belonging in engineering[5]. Tinto's research supports this finding for all college students[6]. Although the loss of students from engineering to other majors in college is not substantially larger than other STEM fields[2], and acknowledging that there are relatively few paths into engineering[7], the lack of diversity in engineering is notable in comparison to several other STEM fields. From the pool of all engineering majors, approximately twenty percent of all bachelors' degrees are awarded to women, and these numbers have marginally *decreased* over the last decade. Additionally, over half of all bachelors' degrees in engineering are awarded to white men[8].

Although the external message of engineering often espouses that "all people can be engineers", the culture of engineering is such that students of non-normative identities may be frequently relegated to only peripheral participation in engineering[9]. Students who have differently-identified gender, race, ethnicity, sexual orientation, disability status, backgrounds or attitudes may not feel they can fully participate in engineering communities of practice, which severely limits their ability to form an authentic engineering identity and reduces the likelihood for individuals from such underrepresented groups who were originally attracted to engineering to persist. This trend further reduces the diversity of students who stay in engineering, propagating diversity issues into the engineering profession. This less diverse population in turn limits the ability of underrepresented groups to identify with engineering and choose engineering in college. Students who do chose engineering, despite barriers in place due to socially constructed demographic identity, still face the issue of acting within a normative engineering culture but may have non-normative attitudinal identities or get treated as such because of being burdened with socially-defined expectations (i.e., not necessarily faithfully representative of their identities). This burden may compound already existing feelings of being marginalized, which may cause many to leave, further exaggerating this negative feedback loop.

Underlying Attitudes and Beliefs

In addition to the persistent issues of underrepresentation along multiple demographic categories in engineering, the lack of diversity may also promote a singular idea of what it means to be an engineer and continue to limit access to those who do not fit that mold[10,11,12]. Because students of diverse backgrounds bring with them alternative mindsets and experiences into an engineering degree program, understanding the underlying attitudes of engineering students early on can provide evidence-based ways to support students with diverse attitudes in their engineering pathways. Additionally, this work can help to understand how different student attitudes and identities may interact, both positively and negatively, with the espoused and tacit culture of engineering to promote belongingness or exclusion, respectively.

Methods

This research project utilizes a longitudinal, sequential, explanatory mixed methods study at four institutions, which represent a variety of institution types (research-intensive, land grant, undergraduate-serving and minority-serving) and geographical regions (southeast, south, Midwest and west), over a period of three years to investigate how students author their identities (both normative and non-normative) within engineering and how these students navigate the cultures of engineering throughout their college years.

InIce Survey Data Collection

In Phase 1, we quantitatively assessed students' identities, motivation, psychological & personality traits, perceived supports and barriers to an engineering career, and other background information using a survey that built on the initial survey development and pilot data[13], to identify normative and non-normative attitudinal profiles of engineering majors. The constructs measured include students' STEM-related identities, personal motivations, grit, and the "Big 5" personality constructs, along with demographic information. Specific constructs used were: (1) Perceptions of the Future (connectedness, instrumentality) (2) Grit (Persistence of Effort, Consistency of Interest), (3) Value, (4) Achievement Goals (performance approach, performance avoid, mastery approach, mastery avoid, work avoidance), (5) Identity (Engineering Identity: Performance/ Competence, Recognition, Interest; Physics Identity: Performance/ Competence, Recognition, Interest; Math Identity: Performance/ Competence, Recognition, Interest) and (5) Personality Constructs (Agreeableness, Extraversion, Neuroticism, Conscientiousness, Openness to Experiences). In addition to the items focused on affective constructs, several survey items assessing demographic information were developed for this project to move away from traditional and somewhat limited definitions of diversity (e.g., a gender binary measure and standard U.S. census questions on race/ethnicity). These items also more authentically captured students' self-identified gender identity, sexual orientation, race/ethnicity, disability status, and parents/guardians' information without framing parents/guardians as necessarily male and female). These items are described below[14]:

- **Gender.** The InIce survey provided the choices of "Male" and "Female" as well as several further options: (1) Transgender, (2) Cisgender, (3) Genderqueer, (4) Agender, and (5) A gender not listed above. Importantly, all of these responses were explicitly prompted as “Please mark all that apply” in order to faithfully and more comprehensively capture students' self-identification. Note also that the final response, “A gender not listed above”, was phrased to avoid implicitly categorizing students as “other” when they identified this category, an important aspect of the validity (fairness) of this item.

- **Sexual Orientation.** This survey focused on self-identification of sexuality rather than attempting to construct it from the responses about romantic or sexual attraction. Similar to the gender item, students were requested to mark “all that apply” from the following: (1) Heterosexual/Straight, (2) Homosexual/ Gay/Lesbian, (3) Bisexual, (4) Asexual, and (5) “A sexuality not listed.”

- **Parental Information.** The survey questioned respondents to identify parent/guardian status in their household while also allowing the student to hold to the expressed gender identities of those household figures. Students could provide information about two parents/guardians (e.g. parent/guardian 1; parent/guardian 2). For each, students were requested to select “all that apply” from the following options, which were the same as students' own gender identification: (1) Female, (2) Male, (3) Transgender, (4) Cisgender, (5), Genderqueer, (6), Agender, and (7) A gender not listed above. Students were also requested to provide information about their parent/guardians' highest level of education by providing (for each): (1) less than high school diploma, (2) High school diploma/GED, (3) Some college or associate/trade degree, (4) Bachelor’s degree, (5) Master’s degree or higher, (6) Don’t know.

- **Race/Ethnicity.** The InIce survey handled the issue of racial/ethnic identification by allowing participants to identify as multiple racial or ethnic groups. Students were prompted to “mark all that apply” with respect to the following particular groups: (1) American Indian or Alaska native, (2) Hispanic, Latino, or Spanish origin, (3) White, (4) Asian, (5) Middle Eastern or North African, (6) Black or African American, (6) Native or Other Pacific Islander, and (7) Another race or ethnicity not listed. Students were also separately requested to “print your specific ethnicities” in an open-ended space provided. Examples of ethnicities were given: “German, Korean, Midwesterner (American), Mexican American, Navajo Nation, Samoan, Puerto Rican, Southerner (American), Chinese”. This combination of questions allowed for both a reliable assessment of individuals' races/ethnicities as well as richer data on ethnicity for future analysis (e.g. “How do students view distinctions in their ethnic identities, and what constitutes the spectrum of identified ethnicities?”)

At the start of the Fall 2015, in the first weeks of the semester, a total of 2,916 surveys were collected from the students enrolled in first year engineering courses at the four participating institutions.

Topological Data Analysis (TDA) to Establish Attitudinal Profiles

A TDA was conducted on the Fall 2015 data to identity normative and non-normative attitudinal profiles using a specific algorithm called Mapper[15]. Mapper iteratively clusteranalyzes the data according to a filtration scheme in order to construct a map which represents the underlying structure of the data. By allowing the data to organically group students based on patterns in the responses, we avoided imposing our own pre-supposed identification of normativity onto students. Thus, common response patterns, or "attitudinal profiles," were allowed to emerge organically from the data, which could then be analyzed through various lenses. This facilitates a conversation about "students who believe X as compared to Y," rather than (for example) "male students, who tend to believe X, in comparison to female students, who tend to believe Y." This analysis provides a novel and rich understanding of our study population and the diversity of incoming attitudes in college engineering programs. Different experiences, values, beliefs, and attitudes that are a result of the intersection of multiple dimensions of identity are allowed to naturally separate themselves. Furthermore, using this profile analysis allowed for new patterns to emerge that would have been previously overlooked. For example, if two groups of respondents were distinct from each other in the attitudinal map but were similar along all measured axes of diversity (e.g., gender and race/ethnicity), it is a signal that the separation between the groups is the result of an intersection with some unconsidered dimension(s) of attitudes or personal characteristics. Because TDA does not presuppose the qualitative or demographic information about the students it analyzes, the technique is robust to unmeasured sources of variance[13].

Findings

Through our research, based both on the literature and our initial results, we have identified the "most salient" variables to be included in the InIce survey by considering factor variances, factor loadings (e.g., construct validity), uniqueness, and interest for theory. We then created a weighted decision matrix: Top weighted – variance of the factor to maximize differences among student responses, uniqueness of the factor to cover the most outcome space in students' attitudes; Medium weighted – theoretical interest of the research team; Lowest weighted – exploratory factor loadings of the questions in each factor. Within the lowest weighted group, we prioritized higher factor loadings[16] because those factors had empirically less measurement error.

Based on the decision matrix, we used the most salient 13 factors variables in the construction of the attitudinal profiles of our participants: (1) Value, (2) Work Avoidance, (3) Connectedness, (4) Perceptions of the Future, (5) Neuroticism, (6) Extraversion, (7) Belongingness, (8) Performance Approach, (9) Instrumentality, (10) Grit – Consistency of Interest, (11) Engineering Identity – Performance/Competence Beliefs, (12) Engineering Identity – Recognition Beliefs, and (13) Physics Identity – Recognition Beliefs. Overall scores and scores for each institution are listed in Table 2 below.

Table 2. A summary of the number of participants and overall means of the 13 most salient attitudinal constructs, and number of participants and means for each partner institution. Attitudinal construct means are reported on a scale of 0 - 6.

Factor	Overall Mean	Partner 1 Mean	Partner 2 Mean	Partner 3 Mean	Partner 4 Mean
Number of Participants	2,916	1104	298	1050	514
Value	4.3	4.2	4.3	4.3	4.3
Work Avoidance	2.1	2.0	2.3	2.1	2.1
Connectedness	4.8	4.9	4.8	4.8	4.8
Perceptions of the Future	4.8	4.8	5.1	4.8	4.9
Neuroticism	2.3	2.4	2.2	2.3	2.2
Extraversion	3.0	3.1	3.0	3.0	2.8
Belongingness	4.8	4.7	5.0	4.9	4.8
Performance Approach	3.7	3.7	3.8	3.7	3.4
Instrumentality	5.4	5.4	5.5	5.3	5.4
Grit – Consistency of Interest	3.4	3.3	3.7	3.4	3.5
Eng. Identity – Performance/Competence	4.6	4.5	4.9	4.6	4.4
Eng. Identity – Recognition Beliefs	4.3	4.3	4.4	4.4	4.2
Physics Identity – Recognition Beliefs	3.8	3.7	3.7	4.2	3.4

Through TDA and a visualization algorithm, the profile analysis identified two normative profiles, four branching profiles, and four outlier profiles. The profiles facilitate an empirically-grounded definition of normative and non-normative attitudes which do not rely *a priori* on the imposition of normativity using traditional markers of societal diversity (e.g. race/ethnicity, gender, etc.). The map that resulted from the Mapper (visualization) algorithm as applied to the 13 salient factors, which led to the identification of these profiles, is shown below in Figure 2.

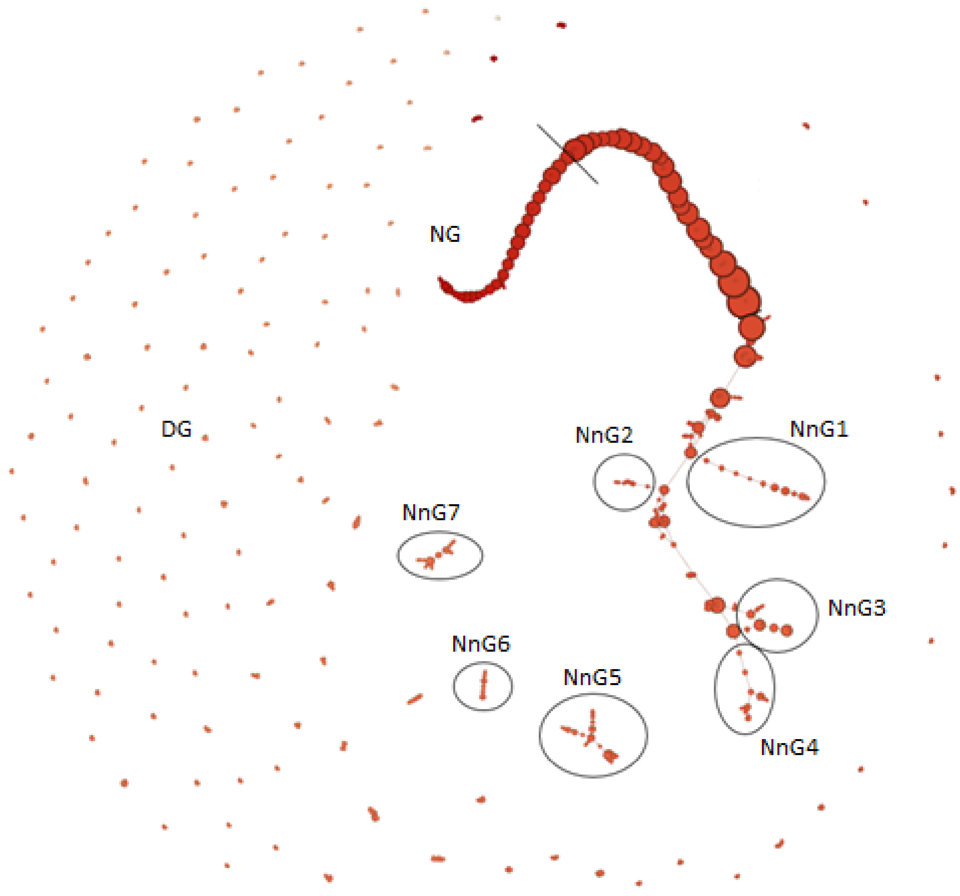

Figure 2. Topological Data Analysis (TDA) map of all InIce survey respondents. The analysis identified a Normative Group (NG), seven Non-normative Groups (NnG1 - NnG7), and the Disparate Group (DG).

The profiles for the Normative Group (NG) and the seven Non-normative Groups (NnG1 - NnG7) are described in Table 3. Results are presented as a comparison to the average factor scores of the NG, with factor scores indicated as significantly higher or lower than the average of the NG.

Table 3. Summary of differences between factor scores for the different groups identified through Topological Data Analysis (TDA). The mean scores and standard errors of the normative group (NG) for each factor is given. Comparisons are made between NG and Non-normative Groups (NnG) 1- 7. Plus (+) or minus (-) signs signify that higher or lower NnG factor score, respectively, when compared to the NG mean. Significance is demonstrated through p-values (*=.05, **=.01, ***=.001).

Factor	**NG (Mean±SE)**	**NnG1**	**NnG2**	**NnG3**	**NnG4**	**NnG5**	**NnG6**	**NnG7**
Value	4.33±0.05	$-^{***}$	$-^{***}$			$-^{**}$		
Work Avoidance	2.05±0.07				$-^{*}$			$-^{***}$
Connectedness	4.90±0.04		$-^{***}$	$-^{**}$				$+^{**}$
Perceptions of Future	5.00±0.04		$-^{*}$					
Neuroticism	2.17±0.05		$+^{*}$		$-^{*}$			
Extraversion	2.97±0.07		$-^{*}$	$-^{*}$	$-^{**}$	$+^{***}$		
Belongingness	4.90±0.04						$+^{*}$	
Performance Approach	3.96±0.05	$-^{*}$		$-^{***}$	$-^{**}$			
Instrumentality	5.45±0.03						$+^{*}$	
Grit – Consistency of Interest	3.55±0.05			$-^{***}$	$+^{**}$			
Engineering ID – Performance/ Competence	4.60±0.05		$-^{*}$		$-^{*}$		$+^{***}$	$-^{*}$
Engineering ID – Recognition	4.48±0.05	$+^{*}$	$-^{***}$		$-^{***}$		$-^{***}$	$-^{***}$
Physics ID – Recognition	4.11±0.06		$-^{**}$			$-^{***}$	$-^{*}$	$-^{*}$

Discussion

We are applying TDA as an analytic technique in educational research, which allows for the development of new clustering methodologies that do not rely on pre-defined assumptions about the data nor on an *a priori* specification of the number or structure of the clusters, thus allowing for the creation of more robust and valid findings which reflect the complex data space spanned by students' responses. Clustering methods work well when datasets decompose reasonably cleanly into distinct groups which are well separated in distance. However, when datasets are essentially continuous and are not well separated or reflect more complex structures and shapes, as occurs in many real-world datasets, clustering techniques do not perform well and may obscure underlying structure. TDA simplifies the data while maintaining the geometric structure allowing the identification of groups which may not naturally be part of an obvious partitioning of the dataset. This technique is particularly appropriate for this application because student attitudinal profiles (especially those that may be common) are not well understood, and the relation between such normative and non-normative attitudes and students’ social identities has been addressed only at a surface level in past research. As a result, intersectional approaches to engineering education have been limited in their efficacy and scope. This project will significantly advance this discourse by providing an empirical, quantitative approach that respects much of the theoretical framing of intersectional lenses for education research.

Further, improving traditional demographic data to move beyond socially constructed perceptions of others allows for the representation of student diversity from the perspective of each participant. Utilizing the student perspective and removing traditional limitations in quantitative demographic questions allows for well-validated student identities to be examined without placing students into inappropriate bins which may not appropriately represent the variance of experience of the contained individuals. This increasingly accurate reflection of diversity provides novel insight into the experiences of students who might otherwise be ignored or unjustifiably lumped in with other students who share some demographic indicator and how residing at the intersection of multiple measures of diversity influences students’ experiences in engineering culture.

From our survey data, we were able to demonstrate that several disparate groups of students exist in terms of their attitudes towards and beliefs about engineering and themselves. While most students fall into a normative group, other groups were identified that either branched off from the normative stem or were entirely separated from the normative stem. These groups are crucial to investigate, since their attitudes differ from what we might think of as “traditional” engineering students. For example, the attitudes of the students contained within Non-normative Group 6 (NnG6) might appear familiar to many engineering educators, as they had higher factor scores related to performance, competence, belongingness, and instrumentality. However, NnG6 scored lower on both recognition factors for both physics and engineering. These students may feel like they can complete the work and that the work is useful to them, but do not feel recognized as engineers.

Although it is tempting to use these survey results as a proactive treatment, for example testing and binning students when they arrive at a university for the purposes of designing personalized treatment, we hesitate to recommend this approach until we fully understand the implications of these attitudes and the extent to which students’ attitudes change over time. However, the understanding that there are different attitudes prevalent within engineering students can be used by educators to help explain ways that students respond to our instructional approaches in unanticipated ways, and to recognize instances where students’ attitudes may be non-normative and/or counter-intuitive. By understanding the nature of the students in our classes, instructors can identify ways to strengthen aspects of instruction and meet the needs of those particular students. Additional descriptions of the normative and non-normative groups are under development and will be described further once the quantitative data can be integrated with qualitative themes.

Future Work

In Phase 2 of the study, students who responded to the InIce survey in Fall 2015 and volunteered their email address are being recruited for interview participation.

Initial interviews were conducted during Spring and Fall 2016 with a total of 22 students across attitudinal profiles. The goal of this interview phase is to describe characteristics of students in particular attitudinal profiles (normative or non-normative), to understand how students within these profiles navigate their engineering programs, and to investigate more deeply their experiences and attitudes. The overall organization of the interview includes the participants' "story" about how they came to be in an engineering program (e.g., How did you get into engineering? Why did you choose your specific major?), followed by their engineering identity (e.g., In your words, what is an engineer? What do engineers do and what skills are needed? Do you see yourself as an engineer?), their sense of belongingness in engineering (Do you feel like you belong in engineering? What characteristics of yourself make you like an engineer?) and other theoretical constructs of interest (namely, the factors that had been used to construct their attitudinal profiles, depending on their individual scores relative to the profile's scores). All students who participated in an initial interview will be interviewed over the next two years.

The final phase of this project will focus on utilizing the findings from Phases 1 and 2 to develop targeted interventions for cultural change and increasing the presence of individuals who identify as part of non-normative groups in engineering. These interventions include the development of a workshop and graduate course for current and future faculty members, respectively, to encourage a discourse towards change in the cultures of engineering. By highlighting and discussing the challenges faced by students of non-normative identities, cognizant steps forward can be described to change how students with diverse attitudinal profiles can be supported in their engineering pathways. The ultimate goal of this research is to highlight new ways to conduct engineering education that will make engineering more inclusive for *all* types of students.

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