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Intersectionality of Non-normative Identities in the Cultures of Engineering

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Intersectionality of Non-Normative Identities in the Cultures of Engineering (InIce)

Introduction to the Project

Traditionally, engineering culture has limited rather than fostered diversity in engineering. To address this persistent issue, we examine how diverse students identify with engineering and navigate the culture of engineering. We define diversity not by making *a priori* categorizations according to traditional demographic information (e.g., race, gender, sexual orientation, etc.), but instead by investigating the variation in students' attitudinal profiles on a host of affective measures. Using these measures, we develop an identification of large, "normative" groups of engineers as well as "non-normative" students who emerge as having distinct attitudinal profiles. This mixed methods study investigates the intersectionality of engineering students' personal identities to understand: How do non-normative groups in engineering form an engineering identity and navigate a culture dominated by limited diversity?

The focus of this paper is on the first phase this project, in which students' identities, motivation, psychological traits, perceived supports and barriers to engineering, and other background information is quantitatively assessed. Pilot survey data were collected from participants enrolled in second semester, first-year engineering programs across three institutions (n = 371). We used topological data analysis (TDA) to create normative and non-normative attitudinal profiles of respondents. As a relatively new and powerful set of analytic methods, TDA clusters variegated data to understand an underlying structure, or topology, which is emergent from the data itself. Our preliminary results show distinct patterns which we subsequently break down according to students' self-identified demographics. Additionally, a subset of participants who completed our quantitative instrument were interviewed about their experiences in and identification with engineering (n = 7). Initial qualitative data analysis indicates that students who reside at the intersectional boundaries of diversity have difficulty identifying role models in engineering and often find themselves expending additional effort as compared to their peers to establish themselves in both engineering and non-engineering communities. Results of this quantitative and qualitative work were used to further refine the quantitative instrument that is to be used in subsequent phases of the project.

Addressing student perceptions that they do not fit in engineering can begin to staunch the exodus of talented individuals from engineering majors. The use of practical methods in this study to understand students' identities as they relate to engineering can be used to attract more students into engineering. An increase in the number of students in engineering will help initiate a much-needed shift toward a more innovative approaches to engineering solutions than may be develop by traditional "normative" groups. We are refining our quantitative instrument to identify and measure engineering students' attitudinal profiles and the underlying analytic techniques. The next phases of the study will assess the target population of engineering students across four institutions in a large-scale quantitative analysis of students' attitudinal profiles (n ~ 2000). Once student clusters are established, exemplar students from each will be longitudinally tracked via qualitative interviews to elucidate the ways in which students navigate engineering cultures.

Background

The lack of diversity in engineering is a persistent issue which hinders the development of well-rounded engineering solutions, 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 freshman year[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 the critical point at which students must be empowered to choose engineering. Otherwise, if the opportunity is lost, transitions into engineering in college are difficult, and the engineering community will largely remain as it is today. While attitudes toward engineering and science careers may begin to form in middle school, high school science and math experiences have a large effect on students' later choice of engineering as a career[3–5].

Additionally, students who leave engineering often do not do so because of inability. These students do not attribute their behavior to limited ability, lack of adequate preparation or a desire not to work hard. Instead, one of the most common reasons students gave for switching was a lack of feelings of belongingness in engineering[6]. Tinto's research supports this finding for all college students[7]. Although the loss of students from engineering when compared to other majors in college is not substantially larger than other STEM fields[2] (and there are relatively few paths *into* engineering), 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 bachelor's degrees are awarded to women, and these numbers have marginally decreased over the last decade. Additionally, over half of all bachelor's degrees in engineering are awarded to white men[8].

While the external message of engineering espouses that all people can be engineers, the culture of engineering is such that students of non-normative identities are often relegated to only peripheral participation in engineering[9]. Students who have differently-identified gender, race, ethnicity, sexual orientation, disability status, background 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 these barriers, still face the issue of acting within a normative engineering culture with non-normative identities which may cause many to leave, further exaggerating this negative feedback loop.

Research Questions and Objectives

The overarching research question for this work is: **how do students who hold non-normative identities position themselves, grow through their education, and navigate the cultures of engineering they experience in college?** To address this research question, the general objective of this study is to investigate methods to incorporate diversity into the engineering community in ways that engage students with non-normative identities to become more active and life-long participants in engineering disciplines. This paper presents our first steps towards answering this research question by identifying, through a quantitative instrument, the attitudinal profiles of normative and non-normative students in engineering. Additionally, qualitative work adds to the development and refinement of our instrument and process of identifying these non-normative groups.

Theoretical Framing

Identity

The concept of identity used in this proposal relates to an individuals' self-beliefs at a particular moment in time and how these responses are stable and/or change. Identity is the authoring of a self within a particular context[10]. In this discussion, the particular context is within an engineering discipline. By understanding this authoring, students' narratives about their belongingness and fit within engineering can be understood. The importance of understanding identity is highlighted by Brickhouse et al.[11], who note that if more diverse students are to enter science and engineering; they need to see themselves as the "kind of people who would want to understand the world scientifically" (p. 443).

There have been earlier calls for an increase in research on engineering identity, including by Brickhouse and others[11,12]. Attainment value, which is related to engineering identity (being an engineer is related to one's "sense of self"), has been found to be important for the persistence of engineering students during their undergraduate programs. Further, it has been found to be more important to engineering persistence than interest or perceived utility[13]. Other research on students' engineering identity has focused on the college years, exploring both engineering and professional identity development. For example, Chachra et al.[14] studied the development of engineering identity during the undergraduate years and found a substantial dependence on the culture of engineering schools as well as students' beliefs about what constitutes engineering practice (e.g. "technical work" versus other aspects). The importance of school culture for the development of an engineering identity has also been found elsewhere[15]. Professional identity development has been another theme of research in recent years. Students who aspire to be engineers have been found to have more distinct professional and occupation-related identities, even at an early age[13,16].

The construct of identity, in our framework, is based on three measurable dimensions of students' beliefs about their performance/competence, the recognition they receive by others, and their interest in a particular subject, in this case, engineering[17–22] . These dimensions richly capture the formation of a student's role identity and can be used to study the creation of an engineering identity. Additionally, the study of identity formation has proven useful in understanding persistence in other domains[23]. This framework for measuring identity has been established through large scale studies in physics and mathematics[18,22].

Traditional roles for students create patterns for access to engineering professions and identity. While non-normative students bring many skills to engineering disciplines such as managing, planning, organizing, coordinating communications, and being cognizant of different perspectives in group decision-making, these features are not always recognized as fundamental engineering skills[24]. The emphasis falls on so-called technical and analytical skills. Non-normative students must not only author their identity as an engineer, but they must live the contradiction with traditional stereotypes surrounding engineering as a masculine, white, heteronormative set of disciplines. Traditionally, the engineering field holds a professional ideology that puts emphasis on mathematical ability and technical expertise. This environment along with the masculine stereotype of engineering contributes to conditions that that can feel particularly unwelcoming to students who do not fit the prescribed mold[25]. The authoring of an engineering identity is not a one-time event during the pursuit of a degree in engineering; rather, it is a continual process engaged in by participants – students, educators, and professionals[10]. Therefore, effective interventions in engineering can impact not only the future generation of engineers, but the current one as well.

Normativity

There are perceptions of a normative culture within engineering which dictates, firstly, that engineers and engineering is a highly technical field that does not focus on or value the social aspects of one's life. This false dichotomy of "social skills" versus "technical skills" within engineering leads to a valuing of technical prowess and a devaluing of social skills (often labeled, pejoratively, as "soft skills") which many students who have non-normative identities bring to the table. This dualism of skills is a false distinction in engineering: technical and social dimensions are integrated components of all engineers' work. While variations of cultural norms within engineering sub-disciplines exist, there are broad assumptions about who can practice engineering that are historically rooted and widespread. The dominant assumptions about engineering is that it is a white, male, heteronormative pursuit in which only "technical skill" is valued. Perceptions among students indicate that the more "technical" or "hard" a subfield of engineering is stereotyped as, the less tolerant it is of those who possess non-normative identities. The process of joining the ranks of practicing engineers makes such cultural norms, assumptions, and identities toward engineering salient even to first-year undergraduate students[26]. The historically-rooted norms of engineering have been hypothesized to create and maintain a normative culture. The powerful, predominantly monolithic, normative culture of engineering can lead to feelings of isolation by those who do not possess such normative values.

Non-normative Identities in Engineering

While there exists a large body of literature articulating how specific minorities in engineering deal with the culture of engineering, there is a notably smaller research literature that attempts to consider how those who reside at the intersection of multiple identities and demographic identifiers navigate engineering culture. Considering inequalities along multiple dimensions of race, class, gender, sex, and sexual orientation, systems of oppression interlock and interweave and that not all people who fall within these intersections experience stigma and oppression the same way[27]. It is difficult for individuals to separate issues from what are traditionally considered (by others) to be two distinct aspects of their identity[28]. For example, if a Black woman experiences bias within engineering, she may attribute her experience to race or gender alone. The intersection of these two social identities are an integral part of who she is as a person and are not distinct. Investigating the intersectionality of students' identities can help us understand how unique individuals – rather than demographically-identified groups – navigate identity formation in the cultures of engineering. Through a data-driven assessment of normative and non-normative identities (rather than an *a priori*, value-laden categorization of individuals into normative and non-normative groups) we will be able to think about new and unique differences than those traditionally studied in engineering education. Through the use of affective markers that are often invisible to research we can draw attention to the experiences of those who are traditionally identified to occupy multiple underrepresentation categories simultaneously.

In the process of exploring normative and non-normative identities, many of the differences in students' self-authored identities may not be readily visible to an external observer. The visibility of students' identities to both researchers, students, and faculty are often deliberate in the level of expression by students[28]. For example, gender and race are typical external identifiers that students cannot choose whether or not to manifest (though they will be treated accordingly), but other facets of student identities, like socio-economic values or sexual orientation, may or may not be expressed openly. As such, students who reside at the intersection of multiple identities, both visible and invisible, may feel marginalized or invisible within cultures in which they reside, even without educators, peers or researchers realizing it[29]. The invisibility that students feel may lead to not receiving the recognition needed to develop a positive, rich engineering identity[30]. Often engineering faculty view an individual’s identity as irrelevant to the engineering workplace. In such a “color-blind” perspective, individual characteristics should play no role in scientific work. However, significant amounts of research demonstrate that no person is “color-blind”[31]. Additionally, faculty may not be influenced by the theoretical developments explaining the importance of students’ identities[28]. Due to the lack of exploration of social aspects of engineering, conversations centered around normative and non-normative values are almost non-existent. Limited conversations about students identities and cultural norms allows the dominant traits of the field's practitioners to perpetuate despite evidence indicating a need for change.

Additionally, this perpetuation of a dominant culture may cause students to feel that they must possess the “right” or dominant engineering values[27].

Those who fall at these intersectional boundaries of identity often feel required to navigate normative culture differently than those who possess more normative identities. Yoshino[32] argues that minority groups are pressured to fit into the norms of the population and keep their stigmatized identity out of view to make life more comfortable for the dominant, normative group. The concept of shifting one's identity to fit the normative identity has been referred to in the literature as “passing” or “covering.” Individuals employ a number of different covering techniques to avoid being the target of “microaggressions in everyday life”[33(p1)], or gestures of hostility, exclusion, and disrespect[27,28]. Some strategies include concealing typical markers associated with a specific identity, including discussions of relationships, and expressions of culture, religion, or various social attitudes. For some the ability to use “passing” techniques facilitates the attainment of a certain level of privilege within the field. Despite this advantage, it has been hypothesized that the inability to be authentic can impact productivity, creativity, and working relationships in addition to long term persistence[27–29].

Understanding how the cultures of engineering may be only partially accepting of diversity and limiting to students who possess diverse identities and perspectives can help to overcome the limitations in existing diversity efforts. Diversity research in engineering often examines students based on the ability to ascribe their belongingness to singular, socially-constructed categories such as those associated to race or gender. Limited work has explored the intersection of race/ethnicity and gender. Work based on gender identity and sexual orientation has only started to come forward in the engineering education literature. Our work will define normative identities in engineering, understand how students’ beliefs and attitudes lead to the formation of normative and non-normative identities, and discover how students who have non-normative identities navigate the cultures of engineering. This perspective on identity allows us to examine students who fit the attitudinal mold of engineering culture, and those who defy this mold. By de-constructing the socially-created boundaries in engineering, we can also examine students who would be considered “minority” students by traditional definitions but in reality fall within a normative attitudinal profile. An examination of students’ self-directed navigation through college will facilitate an understanding of how students reconcile their *a priori* identities with those considered normative by engineering educators. By understanding how students form and navigate identities within the cultures of engineering, targeted interventions can be designed to address the dearth of true diversity in engineering. Creating more diversity in engineering can lead to a broader, stronger, and more creative workforce through the introduction of novel perspectives and educational program designs.

Methods

Qualitative Methods

Pilot data on how students felt empowered to make change in engineering and felt like they belonged in engineering were collected through student interviews of first-year students at a western land-grant institution (9 participants, 13 interviews). The pilot interviews included questions such as: Have you used skills you have gained in your engineering classes? In what ways? Who can be an engineer? Do you feel that you can be an engineer? What experiences made you feel like you belong/don't belong?

Data were analyzed using interpretative phenomenological analysis (IPA) to understand how student experiences in first year engineering programs shaped their feelings of belongingness and agency. IPA has a burgeoning presence in engineering education[34–36]. Specifically, “IPA is concerned with human lived experience, and posits that experience can be understood via an examination of the meaning people impress upon it. These meanings, in turn, may illuminate the embodied, cognitive-affective, and existential domains of psychology[37(p34)] .” In an IPA study, student transcripts are analyzed across three levels: descriptive, linguistic, and interpretative[37]. Descriptive analysis consists of familiarizing oneself with participants’ voices and describing what is being said. Linguistic analysis focuses on how things are said and the language of description (e.g. this level of analysis often looks for the use of metaphors in the description of an experience). Interpretative analysis, shifts the focus from describing to interpreting participant responses through the researcher’s lens. This shift occurs through the self-authoring of questions that warrant further exploration by the research, and then using the researcher’s worldview to interpret participant responses. These data were used to develop survey questions focused on students’ feelings of belongingness in engineering, engineering identity, and agency beliefs about how a career in engineering could make a positive impact in the world.

Quantitative Methods

Topological data analysis (TDA) provides a set of analytical approaches to resolve the problems of unifying intersectionality with quantitative research. At its heart, TDA is a widely-applicable set of techniques for identifying and characterizing the (arbitrary) structures that underlie sets of quantitative data. It has been used in other fields[38,39] but has yet to be applied in the field of education research. Topology in general is concerned with the properties of shapes that are preserved under continuous deformation, including important properties like connectedness. Therefore, a topological understanding of the distribution functions from which we draw our sample data can give us information about the population distribution (e.g. How are students’ responses to attitudinal questions organized and distributed?). After identifying the underlying distribution, we can then look to see how student demographics are distributed on top of this data. In this manner, we allow for the quantitative distribution information to inform how we phrase our discussion of normativity (in attitudes), giving rise to emergent groupings of student responses which still respects the individual and intersectional nature of the students underlying the response data. For example, by collecting attitudinal data on students’ beliefs about engineering, career interests, motivations, etc, TDA allows for an analysis of the data according to the emergent structures present in it (e.g. Where are students’ attitudes clustered in the data space?) before any demographic or other markers of diversity are considered. Subsequently, the "groupings" of student attitudes can be examined to explore where students of different backgrounds show up. This is different from traditional approaches in that we do **not** first disaggregate students according to various demographic indicators of interest (which suffers the problems outlined previously); rather, we allow the attitudinal data to drive the identification of "popular" or "normative" attitudes and motivations.

To characterize normative and non-normative attitudinal profiles of engineering majors, a survey instrument was developed to capture several student factors: students' STEM-related identities [17–22], personal motivations (including items assessing future time perspective[40,41] and goal orientation[42]), career outcome expectations and major intentions[43], agency beliefs[5], grit[44], and personality profile[45], along with demographic information. Many of the survey items measuring demographic information were specially developed for this project. They were designed to move away from traditional definitions of diversity (e.g., allowing either male or female responses for gender expression and traditional U.S. census information on race/ethnicity) to capture students self-identified terms for gender expression, sexual orientation, race/ethnicity, disability status, and parent/guardians' highest level of education (a reliable proxy for socioeconomic status) without framing parents/guardians as necessarily male and female.

The survey was piloted at three institutions with a total of 371 pilot participants enrolled in first year engineering courses at each institution. The data were analyzed for construct validity using exploratory factor analysis and for internal consistency (Cronbach's alpha) and to select questions that helped to reduce survey takers' cognitive load and short enough for students to complete in 20 minutes during the full round of data collection at four research sites.

The pilot data were also used to develop an analytic protocol for applying TDA to identify and characterize normative and non-normative attitudinal profiles within the sample. The research team developed a set of coding packages, code books, and standardized practices to analyze education data using these new techniques. We use a particular TDA algorithm called *Mapper*[46], which iteratively cluster-analyzes the quantitative information according to a filtration scheme to construct a map representing the underlying structure of the data. To illustrate how this algorithm works, consider the analogy of studying trees which grow on a mountain range. Each tree can be labeled by its location (e.g., spatial coordinates). By filtering the locations of the trees according to their elevation, and running this analysis on the subsets of trees in overlapping elevation ranges, we can create a profile of the mountain range that shows the peaks and valleys, with trees on different mountains "clustering together" and connecting to other clusters only at low altitudes (e.g., when the mountains "join" up). After mapping out the mountain, we can then look to see if, for example, trees on different mountains have any systematic differences, such as their genus, average height, longevity, etc. The analogy of studying the location of trees on the mountain is represented schematically in Figure 1 as a companion to the illustrative example described in this paragraph.

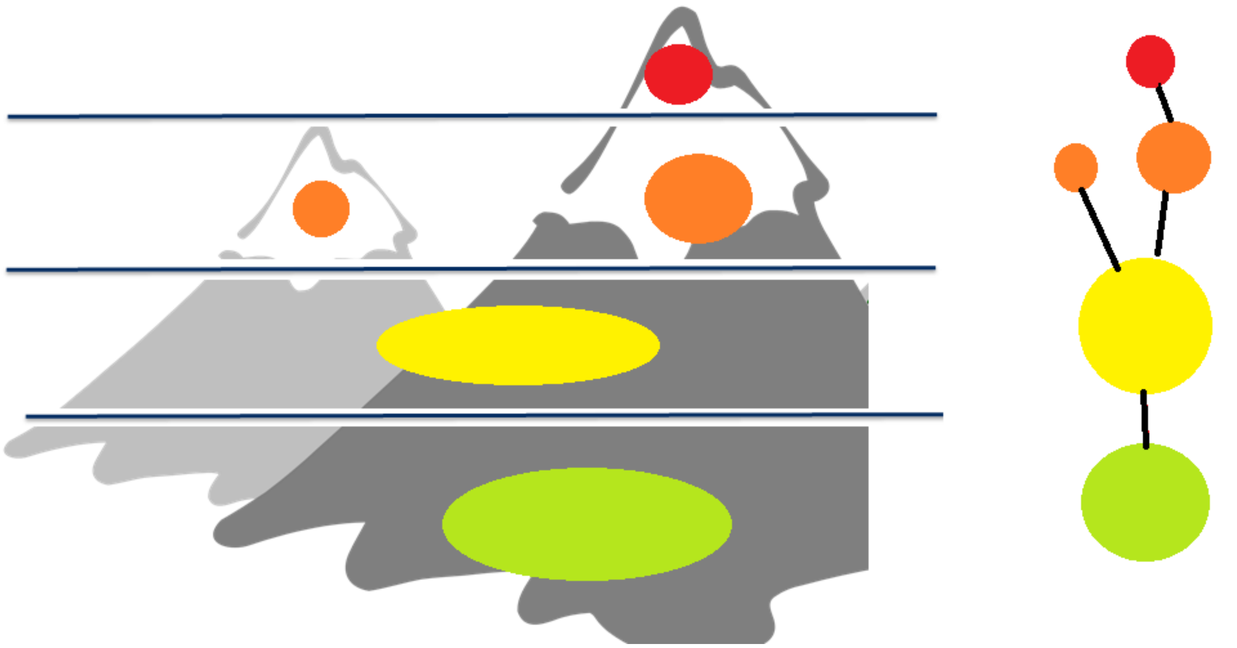

Figure 1: Schematic representation of the illustrative example of use Topological Data Analysis. Here elevation profiles of mountains are examine to understand the different tree populations found in different elevation zones.

In this same way, we use the *Mapper* algorithm to search the quantitative student response data for patterns in the data space of student attitudes using the density of respondents at each point in the data space (e.g., how close data points are to one another). Each student can be represented as a single data point in a high-dimensional space according to their responses, and students with similar responses will then be "close" to each other in this space. These data points are then filtered according to their density, and then transformed into a network of nodes and edges; a single data point can be assigned to multiple adjacent nodes by the clustering algorithm (e.g. in our analogy, trees which appear in overlapping elevation ranges), and this overlap is used to connect those nodes together and form a "map" of the data. Regions of similar density, which are well-separated from other regions of the same density by sections of higher or lower density, will be clustered separately. Sparse data in the intervening space will serve as a bridge between those sections, showing how they are connected and relate to each other.

By allowing the emergent data to group based on patterns in the attitudinal responses, and only afterwards taking demographic factors into consideration (which themselves are constructed as non-mutually-exclusive nominal variables -- as opposed to mutually-exclusive or dummy variables that may unjustly force individuals into one or another category), the research team avoids imposing their own (possibly unconscious) beliefs on students and on their expressions of diverse identities. In particular, this avoids assigning any concept of "normativity" to groups of student; rather, it identifies normativity simply as the location that many students have similar attitudes and identities. In this way, patterns are allowed to emerge organically from the data which can then be further analyzed through an appropriately intersectional lens. This facilitates conversations such as "students who believe X as compared to Y," rather than (for example) "male students, who tend to believe X, as compared to female students, who tend to believe Y," which ultimately gives a much richer and more valid understanding of the individuals involved. Different experiences, values, beliefs, etc. that arise as a result of being at the intersection of multiple dimensions of identity are allowed to naturally separate themselves in this picture of the experiences of the individuals. For example, students may be traditionally identified as coming from one or more underrepresented groups in engineering and, hence, assumed (wrongly) to have some "different" attitudes about engineering, without attention to the diversity within such groups. Instead, the TDA approach allows for the "normative" or popular attitudinal clusters to be first identified in the data, and then traditionally underrepresented individuals will appear within these attitudinal clusters in a way that is faithful to each individual's response (e.g., a traditionally underrepresented student who reflects dominant attitudes towards engineering will appear in that cluster, and not be lumped with other underrepresented students who have other attitudes).

Furthermore, new elements and insight which might have been previously overlooked can likewise manifest themselves in the data patterns. If two groups of students are found to be distinct from each other in the emergent map but, subsequently, appear similar along all measured axes of diversity, this would be a signal that relevant demographic or other experiential information is missing from the data (and from the researchers' expectations of what is relevant to engineering students' pre-college experiences), and that the separation is the result of an intersection on an unconsidered dimension. Because TDA and *Mapper* do not presuppose the qualitative or demographic information about the students it analyzes, the technique is robust to unmeasured sources of variance in the population.

Results and Discussion

Qualitative Results

Analysis of participant interviews is still ongoing. Results presented represent initial emergent themes that will continue to evolve as analysis progresses. Two initial themes have emerged as part of this work: 1.) Recognition from peers and 2.) Exclusion from practice. When discussing belongingness in engineering students often frame their discussion around the ideas of inclusion and having to establish that they belong in engineering. Students, rather than faculty are often portrayed as the gatekeepers of belonging and deciding who gets to be in the engineering club or who is left on the outside:

> "*I feel like it [engineering] wants to be [inclusive]. The professors themselves are really nice – like I'm really excited for my CS [computer science] class. But the way the students act is not necessarily the most welcoming. If I hear one more student use gay as an insult, I'm going to punch them.*" (Mabel, Freshman Black Female)

"The whole [design] project that we are working on in [Freshman Engineering Course]. It made me feel like this is something I can see myself doing in the long run. Little things like, not every single person, but there are a lot of sexist men in engineering. I feel like I have to prove myself to them before I can do anything else." (Jane, Freshman White Female)

Jane and Mabel discuss exclusion in engineering around the ideas of sexism and having to prove to their fellow students. Jane and Mabel are working to earn recognition from their engineering peers. Even as first-year engineering students, where most students have little to no experience in engineering, these two participants were excluded from the engineering community because they are perceived as different. This perceived difference leads to exclusion from the community for Jane and Mabel they are both left out the building phase in an engineering design project on projects by their group members:

"I haven't had to prove myself outside of being female. It's just been that...It's honestly those two guys. I happened to be stuck in their team. They wouldn't let me touch any of the stuff until they were sure I wouldn't cut my finger off. They would let other individuals from other teams who they would let touch and build things and they did not work with these individuals on a daily basis." (Jane)

"There is one guy in the group who for sure does not do any work ever, one guy in the group who only helps when it's building something, and another guy in the group who shows up and helps. When working on the project [female teammate] and I find ourselves doing most of the assignments, like note taking. If we didn't do them we wouldn't get the grades for them. At one point we just stopped giving them credit. And it's like frustrating 'cause we should be building or working on something but we don't start because no one shows up to the meeting and some are like, 'okay reschedule the meeting,' and then we find out by text 30 minutes before, 'Oh I can't show up to the meeting,' and I'm like, 'oh you're an idiot.'" (Mabel)

The roles taken by these two students in their groups reflect previous work found showing that populations that are perceived as different are not valued in the same way as those that are seen as part of the dominant culture[47]. The results of this analysis were utilized by the research team when adapting questions related to belongingness at the peer level in engineering. Belongingness items were asked at course, major, and college levels to attempt to explore the different levels within the institution that students feel like they may or may not belong in engineering. Additionally, the inclusion of these items was further justified by these participants' responses and how their lack of belonging excluded them from participation in engineering tasks and reduced their opportunities to develop engineering skills.

Quantitative Results

We conducted TDA on our pilot data from 371 first-year engineering students across three U.S. institutions. The initial map revealed distinct groups that differed by affective measures, but not by demographic information. The image of the resulting two-dimensional representation of the map is shown in Figure 2. In this image, the map is colored according to the density of the data points. The nodes are sized according to the number of students within each node, and the vertices in the map show overlapping nodes which are similar in relation to adjoining nodes, but differ according to the filter slice chosen.

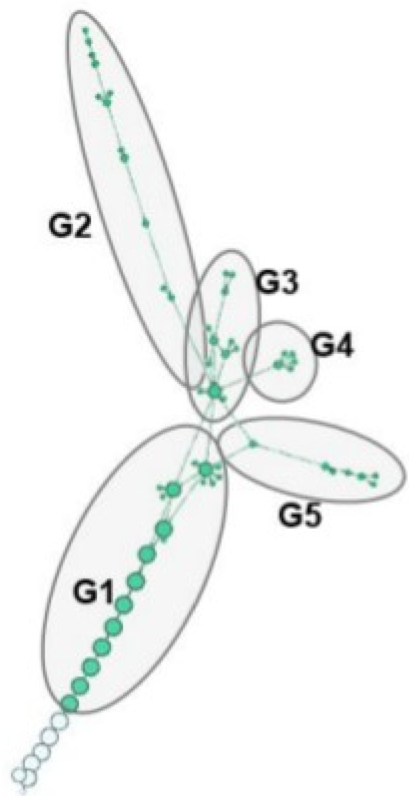

Figure 2: Topological data analysis (TDA) of non-normative groups in pilot study of first-year engineering students.

These groups do not show trends on traditional definitions of diversity based on gender, race/ethnicity, socioeconomic status, etc., but cluster into five groups on a limited set of measures of latent diversity (e.g., identity, motivation, belongingness, and personality). The shading of this network represents the density of the data; the nodes on the lower part of the graph are weakly clustered with the rest of the data and are considered noise. The size of the node represents the number of students included in each overlapping connection. A large branch of students (G1) represents the "normative population" of students. These students have high expectancy for their success in engineering, strong engineering and physics identities, and low agreeableness personality traits. There are a few branching groups which represent "non-normative" groups of students (G2, G3, G4, G5). G2 students feel higher inclusion in engineering, have a strong desire to master engineering material, have lower physics identities, and have higher math identities. G3 students have a strong desire to invent/design things in their future careers, have higher conscientious and intellect personality traits, and the highest identities in math, physics, and engineering. G4 students are strongly oriented toward their future goals and have a strong desire to help others in their future careers. G5 students are more motivated to perform well on tasks, have lower grit, lower personality measures of extraversion and agreeableness, and the lowest physics identities. However, this sample is limited to 371 students at three institutions and is not representative of the U.S. engineering population. Additionally, the number of data points in our pilot sample allowed for psychometric testing, question reduction, and a "proof of concept" that TDA would distinguish groups within our data; however, the small number of data points did not allow for full saturation and spread of the data to detect all possible groups. Our future work includes expanding this sample size at four U.S. institutions to better understand the attitudinal profiles of normative and non-normative students in engineering.

The development of TDA as an analytic technique in educational research allows for the development of new clustering methodologies that do not rely on pre-defined assumptions about the data, thus allowing for the creation of more robust and valid data clusters 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, as many real-world datasets are, clustering techniques do not perform well and may obscure underlying structure. Topological data analysis simplifies the data while maintaining the geometric structure allowing the identification of groups which are not naturally 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 the theoretical framing of intersectionality and student identity.

Restructuring traditional demographic questions to move beyond socially constructed perceptions of others, allows for the representation of student diversity from their perspective. Utilizing the student perspective and removing traditional limitations in quantitative demographic questions allows for intersectionality to be examined on a large scale without essentializing students into bins with which they feel little to no belonging. 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 other demographic factor and how residing at the intersection of multiple measures of diversity influences students' experiences in engineering culture.

This research is the first effort using TDA to understand student data in education research. Prior research that uses TDA has focused on "big data" applications as well as data mining and genetic research. Our conference proceedings and presentations are an introduction for the physics, science, and engineering education communities to engage with a new statistical technique that may prove useful for understanding complex and large datasets.

One long-term benefit of this research project will be an improved understanding of how students navigate engineering, what features of various engineering disciplines are seen as salient to novice practitioners and, thus, the results can be used to improve the effectiveness of recruitment and retention efforts in undergraduate engineering education. Such efforts may, therefore, improve the development and production of the next generation of engineering practitioner.

Future Work and Implications

The next steps in our study include analyzing data collected from a large survey deployment at four U.S. institutions which yielded a sample of 2,966 responses. Once groups of normative and non-normative students are identified and characterized, we will conduct longitudinal study using multiple case studies of selected participants. Participants who provided email addresses and who fall into normative and select non-normative groups will be recruited for interviews about their experiences navigating the cultures of engineering. Prior to conducting interviews an interview protocol will be developed and piloted with engineering students not in the target population. Students will be interviewed at the beginning and end of the Spring 2016 semester; approximately 80 total participants at four institutions are expected. The initial interview will examine past and present experiences in engineering to gain an appropriate baseline of students' experiences in engineering. We will apply a constant comparative method and a phenomenological perspective on these case studies so as to emphasize the essence of students' experiences during their pursuit of an engineering degree. We seek to develop a series of rich and descriptive narratives in the voices of the participants themselves to enrich our understanding of the differences between experiences of students with normative and non-normative identities in engineering.

One of our ultimate goals in this research is to understand how students who may be at the intersection of various modes of oppression experience engineering cultures and self-author their identities, and to act on this understanding. Preserving the voices of the participants will help us meet another project goal to translate our findings to practice. This goal will be accomplished primarily through a pair of workshops for current and future faculty, and a graduate level course, “Diversity in Engineering,” to encourage a discourse towards diversity and cultural change in engineering at our institutions and beyond.

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References

1. Clark Blickenstaff J. Women and science careers: leaky pipeline or gender filter? Gender and Education. 2005;17(4):369–386.

2. Takahira S, Goodings DJ, Byrnes JP. Retention and Performance of Male and Female Engineering Students : An Examination of. Journal of Engineering Education. 1998;87(July):297–304.

3. Tai RH, Liu CQ, Maltese A V, Fan X. Planning Early for Careers in Science. Science. 2006;312(5777):1143–1144.

4. Tai R, Potvn G, Loehr JF, Lloyd SS. The doctoral experiences of students and their advisors in chemistry and physics. In: NARST Annual International Conference. 2008.

5. Godwin A, Potvin G, Hazari Z, Lock R. Identity, Critical Agency, and Engineering Careers: An Affective Model Engineering Choice. Journal of Engineering Education. 2016:In Press.

6. Seymour E, Hewitt N. Talking About Leeaving: Why Undergraduates Leave the Sciences. Boulder, CO: Westview Press; 1997.

7. Tinto V. Leaving College: Rethinking the causes and cures of student attrition. 2nd ed. Chicago, IL: The University of Chicago Press; 1993.

8. Yoder BL. Engineering by the Numbers. 2014.

9. Tonso KL. Engineering Gender - Gendering Engineering: A Cultural Model for Belonging. Journal of Women and Minorities in Science and Engineering. 1999;5.

10. Johnson A, Brown J, Carlone H, Cuevas AK. Authoring identity amidst the treacherous terrain of science: A multiracial feminist examination of the journeys of three women of color in science. Journal of Research in Science Teaching. 2011;48(4):339–366.

11. Brickhouse NW, Lowery P, Schultz K. What Kind of a Girl Does Science? The Construction of School Science Identities. Journal of Research in Science Teaching. 2000;37(5):441–458.

12. Godfrey E, Parker L. Mapping the Cultural Landscape in Egnineering Education. Journal of Engineering Education. 2010;99:5–22.

13. Matusovich HM, Streveler R a, Miller RL. Why Do Students Choose Engineering? A Qualitative , Longitudinal Investigation of Students' Motivational Values. Journal of Engineering Education. 2010;99(4):289–303.

14. Chachra D, Kilgore D, Loshbaugh H, McCain J, Chen H. Being and Becoming: Gender and Identity Formation of Engineering Students. Proceedings of 2008 American Society for Engineering Education Conference. 2008.

15. Tonso KL. Student Engineers and Engineer Identity: Campus Engineer Identities as Figured World. 2006. 273-307 p.

16. Capobianco BM, French BF, Diefes-Dux H a. Engineering identity development among pre-adolescent learners. Journal of Engineering Education. 2012;101(4):698–716.

17. Potvin G, Hazari Z. "The development and measurement of identity across the physical sciences." In: Proceedings of the Physics Education Research Conference. 2013.

18. Hazari Z, Sonnert G, Sadler PM, Shanahan M-C. Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. Journal of Research in Science Teaching. 2010;47(8):n/a–n/a.

19. Cass CA, Hazari Z, Cribbs J, Sadler PM, Sonnert G. Examining the Impact of Mathematics Identity on the Choice of Engineering Careers for Male and Female Students. In: Frontiers in Education Conference (FIE). 2011. p. F2H–1.

20. Potvin G, Beattie C, Paige K. Towards the measurement of undergraduate students' physics identity. In: American Association of Physics Teachers Summer Conference. 2011.

21. Potvin G, Beattie C, Paige K. Building a valid and reliable assessment of physics identity. In: National Association for Research in Science Teaching Annual International Conference. 2012.

22. Cribbs J, Hazari Z, Sadler PM, Sonnert G. Development of an Explanatory Framework for Mathematics identity. In: Proceedings of the Psychology of Mathematics Education-North America (PME-NA) Chapter Conference. 2012. p. pp. 335–338.

23. Carlone HB, Johnson A. Understanding the Science Experiences of Successful Women of Color: Science Identity as an Analytic Lens. Journal of Research in Science Teaching. 2007;44(8):1187–1218.

24. Du X-Y. Gendered practices of constructing an engineering identity in a problem-based learning environment. European Journal of Engineering Education. 2006;31(1):35–42.

25. Jorgenson J. Egineering Selves: Negotiating Gender and Identity in Technical Work. Management Communication Quarterly. 2002;15(3):350–380.

26. Cech E a., Waidzunas TJ. Navigating the heteronormativity of engineering: the experiences of lesbian, gay, and bisexual students. Engineering Studies. 2011;3(1):1–24.

27. Cech E a., Waidzunas TJ. Navigating the heteronormativity of engineering: the experiences of lesbian, gay, and bisexual students. Engineering Studies. 2011;3(January):1–24.

28. Bilimoria D, Stewart A. "Don't Ask, Don't Tell": The Academic Climate for Lesbian, Gay, Bisexual, and Transgender Faculty in Science and Engineering. NWSA Journal. 2009;21(2):85–103.

29. Riley DM. LGBT-Friendly Workplaces in Engineering. Leadership and Management in Engineering. 2008;8(1):19–23.

30. Godwin A, Potvin G, Hazari Z, Lock R. Understanding Engineering Identity Through Structural Equation Modeling (In Press). In: Frontiers in Education Conference (FIE). Oklahoma City, OK; 2013. p. 7.

31. Review CL, Greenwald AG, Krieger LH, Greenwaldt AG, Kriegertt LH. All use subject to JSTOR Terms and Conditions Implicit Bias : Scientific Foundations. 2015;94(4):945–967.

32. Yoshino K. Covering: The hidden assault on our civil rights. Random House Incorporated; 2007.

33. Sue DW, Capodilupo CM, Torino GC, Bucceri JM, Holder AMB, Nadal KL, Esquilin M. Racial Microaggressions in Everyday Life: Implications for Clinical Practice. American Psychologist. 2007;62:271–286.

34. Huff JL, Smith JA, Jesiek BK, Zoltowski CB, Graziano WG, Oakes WC. From Methods to Methodology: Reflection on Keeping the Philosophical Commitments of Interpretative Phenomenological Analysis. In: Frontiers in Education Annual Conference. 2014.

35. Huff JL, Jesiek BK, Zoltowski CB, Oakes WC, Lafayette W. Qualitative Research on Psychological Experience A Starting Point for Using Interpretative Phenomenological Analysis. In: Frontiers in Education Annual Conference. 2015. p. 0–3.

36. Kirn AN. The Influences of Engineering Student Motivation on Short-Term Tasks and Long-Term Goals. 2014. 166 p.

37. Smith JA, Flowers P, Larkin M. Interpretative Phenomenological Analysis: Theory, Method, and research. 1st ed. London: Sage Publications, Inc.; 2009. 226 p.

38. Nicolau M, Levine AJ, Carlsson G. Topology based data analysis identifies a subgroup of breast cancers with a unique mutational profile and excellent survival. Proceedings of the National Academy of Sciences. 2011;108(17):7265–7270.

39. Lum PY, Singh G, Lehman A, Ishkanov T, Vejdemo-Johansson M, Alagappan M, Carlsson J, Carlsson G. Extracting insights from the shape of complex data using topology. Scientific reports. 2013;3:1236.

40. Husman J, Lens W. The Role of the Future in Student Motivation. Educational Psychologist. 1999;34(2):113–125.

41. Stump GS, Husman J, Corby M. Engineering Students' Intelligence Beliefs and Learning. Journal of Engineering Education. 2014;103(3):369–387.

42. Hazari Z, Potvin G, Tai RH, Almarode J. For the love of learning science: Connecting learning orientation and career productivity in physics and chemistry. Physical Review Special Topics - Physics Education Research. 2010;6(1):1–9.

43. Lent R, Brown SD, Hackett G. Social cognitive career theory. Career choice and development. John Wiley & Sons; 2002. 255-311 p.

44. Duckworth AL, Peterson C, Matthews MD, Kelly DR. Grit: perseverance and passion for long-term goals. Journal of personality and social psychology. 2007;92(6):1087–1101.

45. Judge T a, Higgins C a, Thoresen CJ, Barrick MR, Judge, Higgins, Thoresen, Barrick. The Big Five personality traits, general mental ability, and career success across the life span. Personnel Psychology. 1999;52(2):621–651.

46. Singh G, Mémoli F, Carlsson G. Topological Methods for the Analysis of High Dimensional Data Sets and 3D Object Recognition. Methods. 2007:91–100.

47. Felder RM, Baker-Ward L, Dietz EJ, Mohr PH. A Longitudinal Study of Engineering Student Performance and Retention. Proceedings. Twenty-Second Annual conference Frontiers in Education. 1998;84(October):151–163.