What Makes a Smart Engineer? The Cultural Practice of Smartness in First-Year Engineering Classrooms

Objective

Common public messaging promotes the narrative that in order to be an engineer, one must be smart, which is often equated with high performance in math and science (National Academy of Engineering, 2008; Sochacka et al., 2014). Researchers have shown that those who pursue engineering are consistently students who were given messages within their K-12 education that they are smarter than others, and therefore, a good candidate to be an engineer (Kramer et al., 2019). Additionally, researchers have found that within undergraduate engineering classrooms, some people are positioned via cultural construction as simply "not cut out for engineering" or in other words, not smart enough to be an engineer (Secules et al., 2018). The pervasiveness of this narrative is problematic because who gets counted as smart in our educational systems is biased (e.g., racist, sexist) and functions as an exclusionary construct that maintains social hierarchies (Carroll et al., 2019; Gutiérrez y Muhs et al., 2012; Hatt, 2016; Leonardo & Broderick, 2011; Oakes, 2005). To disrupt smartness as a gatekeeping force in engineering, we must investigate how smartness is constructed at individual and sociocultural levels.

The work presented here comes from a larger study designed to understand what, if any, patterns exist in beliefs and identities around smartness and engineering of undergraduate engineering students across institutionalized pathways into engineering. We operationalize institutionalized pathways into engineering as the different contexts where required introductory engineering courses are offered as a stepping-stone to an engineering degree. For this work, the institutionalized pathways were community college, regional campuses, alternative math starting point, standard, residential learning cohort, and honors. We include students from different pathways to 1) increase diversity in our sample and 2) explore structural similarities between the pathways and K-12 tracking, which is understood to perpetuate social inequity (Oakes, 2005). We analyzed parts of two different interviews with engineering students from across pathways to answer the following research questions; *1) what do students believe are the dimensions of being smart in engineering, 2) what (if any) are the differences between how students value these dimensions personally and how they believe they were valued in their introductory engineering course, and 3) what (if any) differences are the differences in which dimensions are important across pathways?*

Theoretical Framework

In our work on smartness in engineering, we draw primarily on the work of Beth Hatt (2012) by operationalizing smartness as a cultural practice. Therefore, smartness is not something that an individual has a certain amount of (e.g., often equated with

intelligence or general ability). Instead, smartness is understood as a cultural practice or a verb; it is something that people in a given context *do to one another* based on implicit judgements rooted in cultural understandings about what it means to think and act intelligently. Ultimately, smartness results in social positioning because it is enacted as a way to situate people relative to one another.

Hatt's theory of smartness was informed by Holland et al. (1998)'s theory of identity and agency in a cultural world, which acknowledges that learning who we are is an act both of individual agency and of sociocultural production. Concretely for our context, this means that as students participate in educational spaces, they are experiencing smartness as a cultural practice from which they learn who is smarter than whom and where they stand in the hierarchy based on perceived smartness (Hatt, 2012). Inevitably, students learn to see themselves as smart relative to others as a combination of both sociocultural forces and their own agency.

Methods

Participants

For this study, we recruited first-year engineering students from the six institutionalized pathways listed above at a large research-focused university in the Midwest. In Spring 2020, we selected 37 participants to interview based on their responses to several open-ended survey questions (e.g., "please describe your educational background") and demographic information. Of the 37 participants, 28 also participated in a second and third interview during the Autumn 2020 and Spring 2021 semesters, respectively.

Data Collection and Analysis: Phase 1

Interviews were semi-structured, one-on-one, and lasted approximately 60 minutes each. Given the COVID-19 pandemic, all but nine first-round interviews were conducted via Zoom. Audio recordings of the interviews were transcribed then reviewed for accuracy. In the first interview, participants were asked to describe their beliefs about engineering, beliefs about smartness, and how (or if) they identify as smart and as an engineer. We analyzed transcripts from the first interview with a structural coding technique to categorize the data (Saldaña, 2015) and organized it by the major constructs of interests (e.g., beliefs about smartness). The unit of analysis was all students, regardless of pathway, to develop a comprehensive understanding. We then broke down each structural category into discrete codes (Miles et al., 2014). We collectively developed emergent codes, which became the "11 dimensions of smartness in engineering" according to our participants' espoused beliefs about what it means to be a smart engineer. Those dimensions are:

- Working hard
- Getting good grades
- Being born with innate ability
- Thinking creatively
- Showing initiative

- Communicating well in teams
- Achieving with little effort
- Applying math and science
- Working efficiently
- Helping others / making the world better
- Solving complex problems

Data Collection and Analysis: Phase 2

Further building on our theoretical perspective and using the results of our first phase, we designed an interview prompt for our third interview. These interviews were similar in format to the first interviews and were conducted a year later. Specifically, we presented the 11 dimensions of smartness in engineering as a list and asked participants to rank order them twice, once based on each of the following:

> 1) what they believe was most important to be recognized as being smart enough for engineering in their first-year engineering course sequence (sociocultural forces)
>
> 2) what they personally believe is most important to be smart enough for engineering as an engineer (individual agency)

We designed this prompt to understand the relationship between valued dimensions of smartness in first-year engineering classroom versus their own personal value of each dimension. We followed the ranking with probing questions to understand their rationale.

We analyzed the quantitative data taken during the third interview to find the overall average rank for all students (including all pathways) per dimension of smartness for both classroom and personal beliefs. We then conducted a paired t-test with a 95% confidence interval to determine statistical significance between how students ranked the dimensions based on what they felt was recognized in the classroom versus what they personal feel is important to being a smart an engineer. We then drew on the qualitative data to help contextualize and make sense of their responses.

Results

In Table 1, we present statistical results. Figure 1 is a graphical representation of the results. In this section, we present a few key findings regarding the items where statistically significant differences were found. We will expand upon these findings in the full paper including a more nuanced discussion using the qualitative data.
Overall, we found a statistically significant difference in how students ranked 6 of the 11 dimensions of smartness based on what they believe is recognized as smart in their first-year engineering classrooms versus what they personally feel makes them a smart engineer. *Working hard*, *showing initiative*, and *making the world better or helping others* were ranked as personally making students feel like a smart engineer at

significantly higher levels than they were ranked as recognized as smart in the classroom. Whereas, *being born with innate ability*, *achieving with little effort*, and *getting good grades* were said to be more important when recognizing smartness in the classroom.

Getting good grades: Overwhelmingly, getting good grades was the main way in which students said people are recognized as smart in first-year classrooms. Even for participants who ranked "getting good grades" as lower still described the items they ranked above as leading to good grades. For example, students would say that if one was recognized for communicating well in teams and solving complex problem, then they would ultimately get a good grade, which was (again) *always* understood as important in engineering classrooms to be recognized as smart. Although many students still used grades as a way to personally feel like a smart engineer, they also noted the limitations of using grades as the sole measure of their abilities as an engineer and were often resistant to the emphasis placed on grades in their classrooms.

Working hard and showing initiative versus innate ability and achieving with little effort: Working hard (and showing initiative) were two of the dimensions that students ranked highly as making them feel like a smart engineer, whereas being born with innate ability and achieving with little effort were ranked as the least important. However, students still indicate that in classrooms innate ability and achieving with little effort is valued. Even students who individually valued their own hard work, often spoke of students who appeared to achieve with little effort as "smarter" indicating that there are implicit assumptions linking smartness to innate abilities.

Making the world better / helping others: Overwhelmingly, making the world better or helping others was ranked as least importance in terms of what is recognized as smart in first-year engineering classrooms. Although there was a significance difference with students personally prioritizing making the world better as higher in terms of their own identities as smart engineers, it was still one of the most devalued dimensions. Many students even questioned if it should be included as a dimension of smartness in engineering stating that it was more of what makes someone an "ethical" or "moral" engineer. This is important to note because it reflects how smartness is culturally produced in engineering in ways that create a boundary around what *type* of smart is considered acceptable in engineering.

Since prior research has shown that culture, norms, and expectations can vary when students are tracked according to perceived ability such that they influence students' self-beliefs (Nunn, 2014; Oakes, 2005), we also explored the differences between the various pathways in engineering, which are graphically presented in Figures 2 and 3. Based on our analysis, those in the less prestigious pathways place less emphasis on

the role of innate abilities both inside and out of the classroom. These findings will be further expanded upon in the full paper.

Conclusions and Scholarly Significance

Building upon prior research within engineering education that indicates the salient role of smartness (or ability) in engineering (Godfrey & Parker, 2010; Kramer et al., 2019; Secules et al., 2018; Sochacka et al., 2014), our work contributes empirical data of what students believe are the dimensions of being smart in engineering. Through our analysis, we developed 11 dimensions representing these beliefs and found significant differences for six of the 11 dimensions between how they were important to personally feel like a smart engineering and how they were important to be recognized as smart in their first-year engineering classroom. The differences in rankings are concerning because they highlight how smartness is being produced in engineering classrooms in ways that prioritize grades, devalue helping others, and do not align with students' perspectives of what it means to be a smart engineer.

As educators and researchers, we need to consider how we are contributing to the cultural production of smartness in engineering programs as it has significant implications for how students learn and, as shown in this data, is likely at odds with students' own beliefs and values. These beliefs and cultural constructions have great ramifications for who is retained and recognized as "capable" in engineering and who is pushed out of the discipline or labeled as "not cut out for engineering" (Secules et al., 2018). As the discipline aims to grow and be more inclusive, considerations around smartness and its impact are essential for cultivating equitable educational systems within engineering at both the individual and cultural levels.

Tables and Figures

Table 1 – Dimensions of Smartness in Engineering – Statistical Overview

	What students believe is recognized as smart in class		What students believe personally believe makes them smart		
	Average Rank	**SD**	**Average Rank**	**SD**	**p-value**
Working hard*	4.8	2.7	3.3	2.1	0.01
Born with innate ability*	7.6	3.0	9.3	2.1	0.01
Showing initiative*	6.8	2.8	5.2	2.9	0.01
Achieving with little effort*	7.0	3.2	8.9	2.1	0.01
Working efficiently	5.2	2.6	4.4	2.7	0.11
Solving complex problems	4.1	2.6	4.9	2.7	0.16
Getting good grades*	4.1	3.1	6.9	2.9	0.00
Thinking creatively	5.4	2.9	4.2	2.6	0.06
Communicating well in teams	6.1	2.7	5.7	2.8	0.61
Applying math/science	6.3	2.6	6.1	2.7	0.70
Making the world better/helping others*	8.6	2.9	7.0	2.8	0.01

*Notes: 1=most important and 11=least important, * indicates statistical significance (p<0.05)*

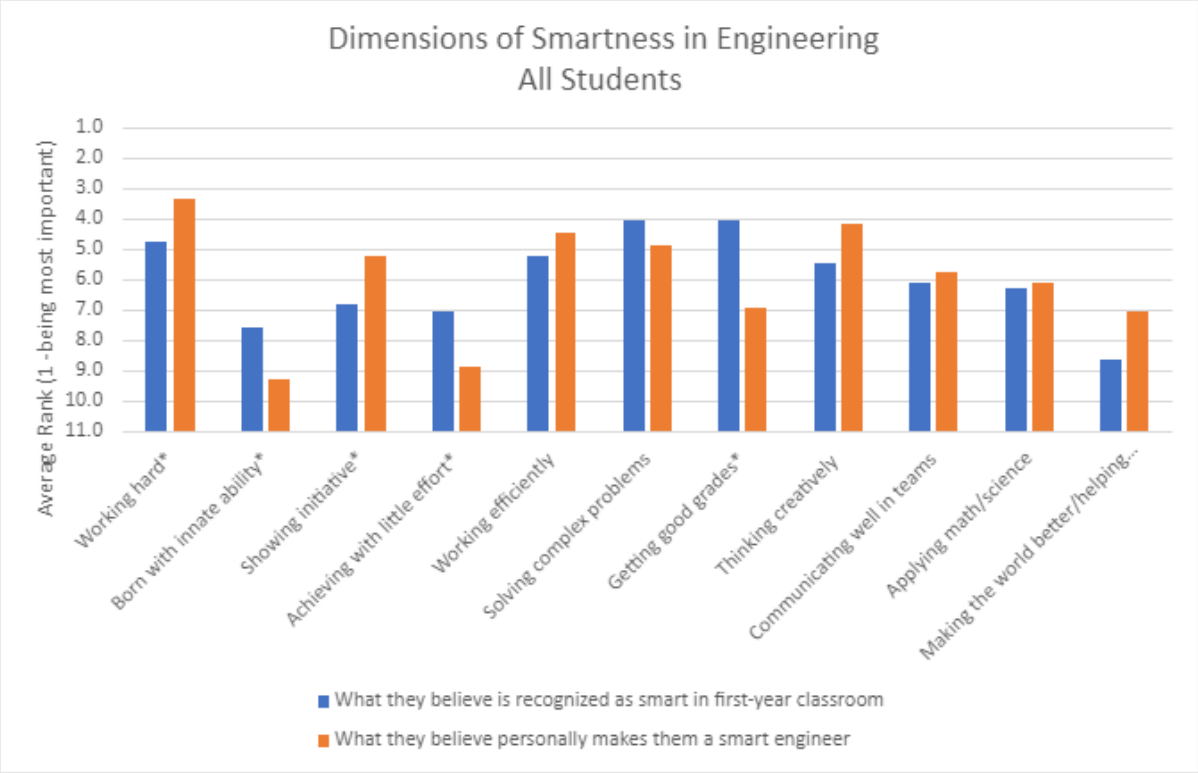

Figure 1 – Average Rank of the “Dimensions of Smartness in Engineering”
*Note: * indicates statistical significance*

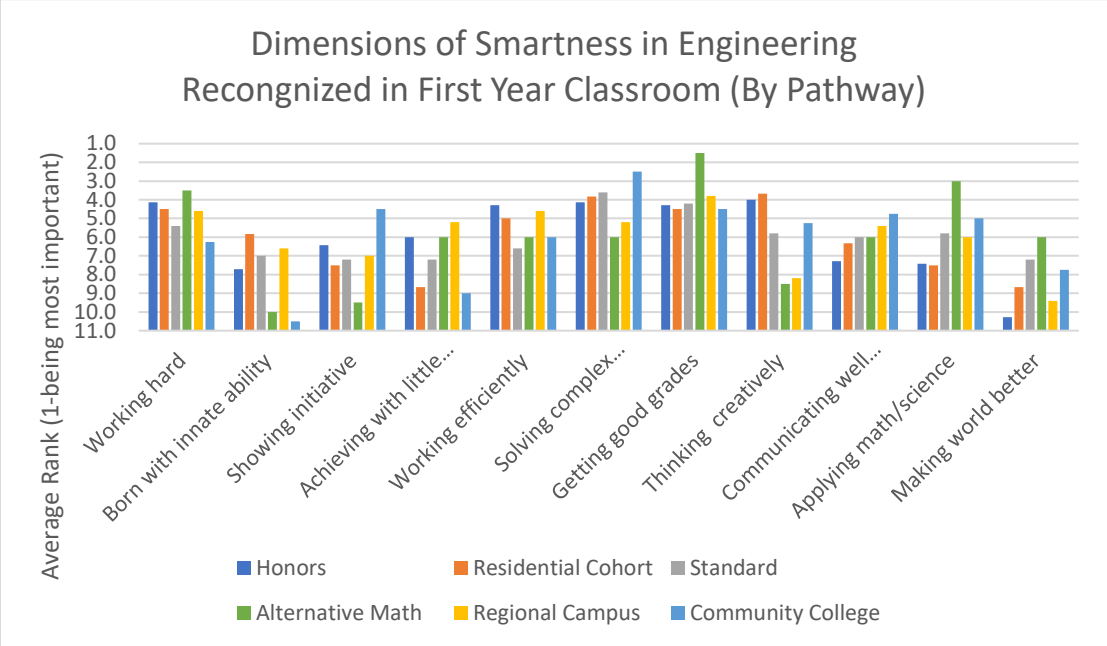

Figure 2 - Average Rank of “Dimensions of Smartness in Engineering” as What is Recognized as Smart in First-Year Engineering Classroom by Pathway

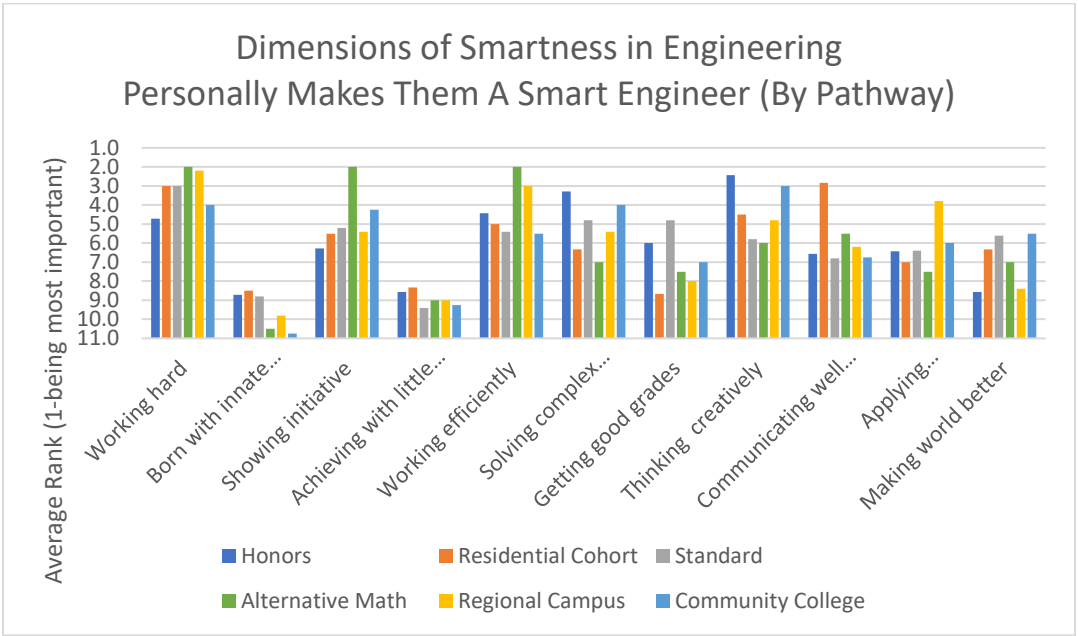

Figure 3 - Average Rank of “Dimensions of Smartness in Engineering” as What Makes Students Feel Like a Smart Engineer by Pathway

References

Carroll, T., Kramer, A., & Dringenberg, E. (2019). *Intelligence and Smartness in Engineering: A Gatekeeper to Diversity and Inclusion* The Collaborative Network for Engineering and Computing Diversity, Crystal City, Virginia.

Godfrey, E., & Parker, L. (2010). Mapping the cultural landscape in engineering education. *Journal of Engineering Education*, *99*(1), 5-22.

Gutiérrez y Muhs, G., Niemann, Y. F., González, C. G., & Harris, A. P. (2012). *Presumed incompetent: The intersections of race and class for women in academia*. Utah State University Press.

Hatt, B. (2012). Smartness as a cultural practice in schools. *American Educational Research Journal*, *49*(3), 438-460.

Hatt, B. (2016). Racializing smartness. In: Taylor & Francis.

Kramer, A., Wallwey, C., Thanh, G., Dringenberg, E., & Kajfez, R. (2019). A Narrative-Style Exploration of Undergraduate Engineering Students' Beliefs about Smartness and Identity. 2019 IEEE Frontiers in Education Conference (FIE), Cincinnati, Ohio.

Leonardo, Z., & Broderick, A. (2011). Smartness as property: A critical exploration of intersections between whiteness and disability studies. *Teachers College Record*, *113*(10), 2206-2232.

Miles, M., Huberman, A. M., & Saldana, J. (2014). *Qualitative data analysis: a methods sourcebook*. Sage.

National Academy of Engineering. (2008). *Changing the conversation: Messages for improving public understanding of engineering*. National Academies Press.

Nunn, L. M. (2014). *Defining student success: The role of school and culture*. Rutgers University Press.

Oakes, J. (2005). *Keeping track*. Yale University Press.

Saldaña, J. (2015). *The coding manual for qualitative researchers*. Sage.

Secules, S., Gupta, A., Elby, A., & Turpen, C. (2018). Zooming Out from the Struggling Individual Student: An Account of the Cultural Construction of Engineering Ability in an Undergraduate Programming Class. *Journal of Engineering Education*, *107*(1), 56-86.

Sochacka, N., Walther, J., Wilson, J., & Brewer, M. (2014). Stories 'Told'about Engineering in the Media: Implications for attracting diverse groups to the profession. 2014 IEEE Frontiers in Education Conference (FIE) Proceedings,