Exploring Undergraduate Engineering Students' Changing Beliefs About Smartness in Engineering

Cassie Wallwey
Department of Engineering Education
Virginia Polytechnic Institute and State University
Blacksburg, VA, USA
cwallwey@vt.edu

Amy Kramer
Department of Engineering Education
The Ohio State University
Columbus, OH, USA
kramer.659@osu.edu

Rachel Kajfez
Department of Engineering Education
The Ohio State University
Columbus, OH, USA
kajfez.2@osu.edu

Emily Dringenberg
Department of Engineering Education
The Ohio State University
Columbus, OH, USA
kramer.659@osu.edu

***Abstract*—What does it mean to be "smart" in an engineering classroom? How do engineering students make sense of themselves as smart enough to be engineers? The development of shared beliefs about what it means to be "smart" and where you rank compared to others is a result of smartness as a cultural practice. With the cultural practice framing, smartness *is not a noun* – something that someone possesses a certain amount of, but rather *it is a verb* – something that is actively happening to and with others in context. The interactions between individuals result in shared beliefs about what it means to be smart. Specifically, when we participate in smartness as a cultural practice, we learn what is recognized as smart and our place in the relative hierarchy of smartness.**

Beliefs about how to be a smart engineer become particularly impactful to students when navigating educational experiences in an area of study in which "being smart" is synonymous with the field. Engineers are constructed as "smart" in society, where the pervasive belief is that ability is something you either have or you don't. But as students transition into undergraduate engineering programs, how does their participation in the cultural practice of smartness contribute to their beliefs about what it means to be a smart engineer and their identities as smart and as engineers? Our study generated empirical evidence for how.

We conducted three interviews with 25 engineering students over the course of their first and second years in an undergraduate engineering program. In the first and third interviews, we asked participants explicit questions about their beliefs and identities related to smartness and engineering. Analysis to compare the beliefs expressed in students' first and third interviews revealed that about half of the 25 participants demonstrated notable change in their beliefs of what it meant to be a smart engineer. We present empirical evidence characterizing the ways in which undergraduate engineering students' beliefs about what it means to be a smart engineer changed over the course of a year for 5 of the 25 participants. We explored these 5 participants' changing beliefs through a lens of cognitive dissonance theory. Cognitive dissonance is the misalignment between two or more of a person's beliefs and/or behaviors. People experience discomfort with dissonance and therefore work to resolve the misalignment. One way in which someone's dissonance can be resolved is by a person changing their beliefs. Using this lens, we discuss how the changes to participants' beliefs may be an artifact of students' need to resolve the dissonance between the shared beliefs and ranking in a smartness hierarchy produced during their participation in smartness as a cultural practice in the context of pre-college education and engineering education. We also make recommendations to engineering educators on how to engage in the cultural practice of smartness in a way that allows for the growth and development of students' beliefs of what it means to be "smart" in engineering.

Keywords—engineering student beliefs, smartness in engineering, changing beliefs

I. Objective

Beliefs are fundamental to the way people behave and to our educational systems. Researchers have shown that beliefs are a way that we understand and make sense of the world [1]–[5]. In this work, we explore the beliefs that undergraduate engineering students hold about what it means to be smart in engineering as they participate in their undergraduate engineering program. This was done to identify if students entering their engineering programs through different institutionalized pathways (e.g., community college, satellite campus, honors tracks, etc.) hold different beliefs about smartness in engineering based on their pathway, similarly to how K-12 tracking practices have been shown to perpetuate inequity and students' beliefs about themselves as learners [6].

We focus on beliefs about smartness because the idea of "smart" is very salient in engineering [7]. In other words, it is commonly understood that to be an engineer, one must be recognized as smart. Indeed, researchers have shown those who pursue engineering are consistently students who were recognized as smarter than others in their K-12 education [8], and students and faculty in engineering believe that engineers are high academic achievers [9]. However, smartness can function in oppressive ways (e.g., who gets recognized as smart is biased) and maintain inequitable hierarchies [6], [10]–[13]. The work presented in this manuscript comes from a larger study designed to understand what, if any, patterns exist in the beliefs about smartness and engineering of undergraduate engineering students from within and between different institutionalized pathways into undergraduate engineering programs. To be clear, beliefs are a broad and complex research construct [4]. In this work, we understand beliefs as playing an important role in culture or social systems [1], [3]–[5].

We analyzed parts of two different interviews with engineering students during 1) the second semester of their first year and 2) the second semester of their second year to address the following research questions:

1) *How do students' beliefs about what it means to be a smart engineer change between their first and second year in an engineering program?*

2) *What (if any) are patterns that exist amongst the students whose beliefs about what it means to be a smart engineer change?*

II. Theoretical Framework

We draw on the work of Beth Hatt [14] to operationalize smartness as a cultural practice. Through this operationalization, smartness is not simply an individual or inherent trait but rather a cultural practice. In other words, smartness is something that people embody within a given context and do to one another based on implicit judgements about what they think it means to behave or think intelligently. In the context of education, as students participate in educational spaces, the cultural practice of smartness results in a shared beliefs about what it means to be smart in that context and a positional identity relative to others in a hierarchy of perceived smartness. Since the cultural practice of smartness is occurring within larger systems of power and privilege (e.g., racial and gender stereotypes about ability), smartness has significant implications in terms of equity. For example, in Hatt's [14] ethnographic work of elementary school classrooms, she found that the Black boys in the classroom received less recognition from their teacher and were positioned as less smart than their white peers despite similar behavior.

We choose to focus on the changing beliefs of engineering students about what it means to be a smart in engineering from their first year to their second year to begin to understand the cultural production of smartness specifically within the context of undergraduate engineering.

III. Methods

A. Participants

In Spring 2020, we selected 37 participants to interview based on their responses to several open-ended survey questions and demographic information. We purposefully sampled to get a diverse set of participants with regards to their academic pathway into engineering, as engineering students at the institution this research was conducted at have six institutionalized pathways into the engineering program: community college, regional campus, alternative math entry point, standard track, scholars track, and honors track. We were interested in sampling across pathways because we wanted to 1) increase the diversity of educational experiences in our sample and 2) explore any similarities between institutionalized pathways into engineering and inequitable K-12 tracking practices [6]. Of the 37 participants, 25 participated in both a second and third interview during the Autumn 2020 and Spring 2021 semesters, respectively. These 25 participants that participated in all three interviews were the subjects of the data analysis completed to answer the research questions regarding a change in beliefs of what it means to be smart in engineering across one year of their engineering program.

B. Data Collection and Analysis

All individual interviews were semi-structured, one-on-one, and lasted approximately 60 minutes. While three interviews were conducted with each of the 25 participants, this analysis focused on the first and third interviews, as those interview protocols had questions specifically related to beliefs about smartness and engineering.

TABLE I. Beliefs of what it means to be smart in Engineering

Beliefs of what is considered smart in Engineering	Belief Group
Achieve with little effort	Innate ability / Grades
Getting good grades	
Being born with innate ability	
Thinking creatively	Skills
Applying math and science	
Solving complex problem	
Working efficiently	
Showing initiative	Dedication
Working hard	
Helping others/Making the world better	Social
Communicating well in teams	

C. Interview 1 Data Collection & Analysis

In the first set of interviews, 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 using a structural coding technique to categorize the data [15] and organized it by the major constructs of interests (e.g., beliefs about smartness). We then broke down each structural category into discrete codes [16]. From this analysis 11 common beliefs about what is considered smart in engineering emerged according to the participants' espoused beliefs about what it means to be a smart in engineering [17]. We then grouped the common beliefs using a protocol coding technique [15] to help organize the different beliefs that undergraduate engineering students held about what it means to be smart in engineering. These groups and beliefs are shown in Table I.

D. Interview 3 Data Collection & Analysis

Building on the results from the analysis of the first set of interviews, we designed an interview prompt where we presented the 11 common beliefs about what it means to be smart in engineering as a list and asked participants to rank order them twice: once based on what they believe was most important to be recognized as being smart in engineering in their first-year engineering course sequence and the second time based on what they personally believe is most important for being smart in engineering. We followed the ranking with probing questions to understand their rationale and to help make sense of their rankings. Using results of the analysis from interview one, the rankings from interview three, and detailed analytic memos crafted by our research team [18], we performed a comparative analysis of the participants' beliefs about what it means to be smart in engineering from their first interview to their third interview using a data visualization display technique [18]. Three researchers performed the analysis individually and then met to iteratively and collaboratively 1) identify the participants who expressed notable change or explicitly

discussed conflicting beliefs and 2) develop the data visualizations for the identified participants changing beliefs.

IV. Results & Discussion

Between interviews one and three, about half (12 out of 25) of the participants were identified as describing a notable change in their beliefs about what it means to be smart in engineering, or the development of new beliefs that conflict with their original beliefs about what it meant to be smart in engineering. Five participants were identified as experiencing both a change in beliefs and conflicting beliefs.

A. Research Question 1: Changing beliefs

Broadly, we found that the changes were centered around students' beliefs regarding the relationship between being smart and getting good grades with the students expanding or shifting their definitions of smart to encompass more than just getting good grades or high academic achievement / performance. Those who demonstrated a change in their beliefs about what it means to be smart in engineering based on conversations in interview 1 and interview 3 did so in a variety of ways. Some students simply noted that their beliefs had expanded (e.g., maintaining their belief about innate ability, but also expressing their understanding that "being smart" is a social construct.) Other students changed their beliefs (e.g., shifting from grades and performance to dedication and problem-solving skills being indicative of someone who is a smart engineer). There were also a few students who noted that new beliefs they were developing were in conflict with previous beliefs they held (e.g., what they believed to be the result of innate ability might be the result of hard work).

With nearly half of our participants expressing some change in their beliefs regarding what makes someone smart in engineering, we began to wonder what might inform these students' changing beliefs, as this was not a research question originally driving the research, and so therefore we never explicitly asked students to reflect on their changing beliefs and why those changes may have occurred.

B. Research Question 1 (Cont.): Changing beliefs of focal participants

As noted previously, out of the 12 participants of which content from interviews 1 and 3 pointed to a change in beliefs about smartness and what it means to be smart in engineering, 5 participants were observed to have conflicting beliefs which led us to consider cognitive dissonance as a possible explanation for students' changing beliefs.

When a person experiences cognitive dissonance, there is an inconsistency (dissonance) between beliefs and/or behaviors, and this dissonance is often uncomfortable [19] and people are driven to resolve this inconsistency to return to a comfortable state. One way dissonance can be resolved is by changing beliefs to reduce the inconsistency between beliefs/behaviors [19]. By leveraging cognitive dissonance theory, we can gain insight into how the cultural practice of smartness informs dissonance related to what it means to be a smart engineer and contributes to students evolving beliefs about smartness within engineering. To begin to unpack and understand the reasoning behind students' changing beliefs we drew on the theory of cognitive dissonance and mapped the changing beliefs of the five participants (we'll call them "focal participants" for the remainder of this paper) that expressed both notable changes in their beliefs and explicitly discussed the existence of conflicting beliefs. Refer to Tables II-VI for the data visualization of each participant's changing beliefs.

TABLE II. Sarah's Beliefs about Being Smart in Engineering

Dimension of Smartness in Engineering	Interview 1	Interview 3
Achieve with little effort	X	
Getting good grades	X	
Being born with innate ability	X	
Thinking creatively	X	X
Applying math and science	X	X
Solving complex problem	X	X
Working efficiently		X
Showing initiative		
Working hard		X
Helping others/Making the world better		
Communicating well in teams	X	X

TABLE III. Hailey's Beliefs about Being Smart in Engineering

Dimension of Smartness in Engineering	Interview 1	Interview 3
Achieve with little effort	X	
Getting good grades		
Being born with innate ability	X	
Thinking creatively	X	X
Applying math and science	X	X
Solving complex problem	X	X
Working efficiently		X
Showing initiative		X
Working hard	X	X
Helping others/Making the world better		X
Communicating well in teams		X

TABLE IV. Charlie's Beliefs about Being Smart in Engineering

Dimension of Smartness in Engineering	Interview 1	Interview 3
Achieve with little effort		
Getting good grades		
Being born with innate ability	X	
Thinking creatively	X	X
Applying math and science	X	X
Solving complex problem	X	X
Working efficiently		X
Showing initiative		
Working hard	X	X
Helping others/Making the world better		
Communicating well in teams	X	X

TABLE V. Apple's Beliefs about Being Smart in Engineering

Dimension of Smartness in Engineering	Interview 1	Interview 3
Achieve with little effort		
Getting good grades	X	
Being born with innate ability	X	

Dimension of Smartness in Engineering	Interview 1	Interview 3
Thinking creatively	X	X
Applying math and science	X	X
Solving complex problem	X	X
Working efficiently	X	X
Showing initiative		X
Working hard	X	X
Helping others/Making the world better	X	
Communicating well in teams	X	

TABLE VI. DAVID'S BELIEFS ABOUT BEING SMART IN ENGINEERING

Dimension of Smartness in Engineering	Interview 1	Interview 3
Achieve with little effort		X
Getting good grades	X	X
Being born with innate ability	X	X
Thinking creatively	X	X
Applying math and science	X	X
Solving complex problem	X	X
Working efficiently	X	X
Showing initiative	X	
Working hard		
Helping others/Making the world better		
Communicating well in teams	X	

In the first interview all focal participants indicated that they believe that being a smart engineer means some combination of having innate abilities, particularly in math and science, achieving with little effort, and getting good grades. The participants did also discuss other skills necessary to be a smart engineer (e.g., creativity, problem solving, math and science skills, communicating in teams), but when directly asked what skills they have related to being a smart engineer, they indicated a belief in the importance of innate ability. For example, Sarah said:

"I have a natural brain that tends me towards math and physics and understanding."

In the third interview, the focal participants showed a change in their beliefs about what it means to be a smart engineer. The participants tended to maintain beliefs that things like creativity, problem solving, and applying math and science skills are important, but all participants (except David) moved away from believing that innate ability, achieving with little effort, or getting good grades defined being smart in engineering. Instead, they replaced it with working efficiently, working hard, and/or showing initiative.

We explore this change in the students' beliefs through the lens of cognitive dissonance theory. In the first interview, the participants expressed that being smart includes getting good grades and doing so with little effort through innate ability. We then start to see some of the participants struggle academically; their grades are not as high as they want them to be. This experience starts to introduce dissonance between their belief that they are smart and what they originally defined as what it means to be smart (getting good grades with little effort). We posit that to resolve this dissonance and maintain their identity as smart, they must shift or change their beliefs about what it means to be smart – they shift away from relating smartness to getting good grade and instead about working efficiently. For example, Sarah said:

"So during my fall semester, I was just like, I'm stupid. When I failed a midterm that was my initial first thought. But you know, looking back, I don't really see that as that way, I've seen the grades as how well I prepared for the test. I don't really see that as my smartness level anymore."

By believing that smartness is working efficiently, and grades are a reflection of hard work more than smartness, the participants are able to make sense of some of the dissonance in their beliefs and preserve their identity as smart. For example, a lower grade no longer means that they are not as smart as a peer, instead it could mean that they did not have as much time to study or chose to allocate their time differently. This shift in their beliefs allows them to justify getting a lower grade and maintain an identity as smart. Yet through the belief in smart being working efficiency, they can still maintain the notion that those who are most efficient, which is typically associated with being able to achieve while putting in the least amount time or understanding concepts quickly (i.e., presumably because of one's innate abilities) are still the smartest.

C. *Research Question 2: Patterns amongst students who experienced change*

When exploring who experienced a change in beliefs across institutionalized pathways into engineering, we found that most students who experienced a change in beliefs about what it means to be a smart engineer (9 out of 12) participated in the Honors and Scholars pathways into engineering. A summary of the number of students whose beliefs changed can be found in Table VII.

We found that most students who experienced change in their beliefs about what it means to be smart in engineering are students who entered engineering through the Honors or Scholars pathways. The majority of students in these pathways into engineering gained access to these pathways by demonstrating their academic ability through traditional measures of academic achievement such as GPA and standardized test scores [20]. High GPA and standardized test scores likely also led to them being viewed as smart or smarter than others by their peers and educators in high school [21]. As these students navigated their new educational environment in their pathways with other high academically achieving peers, they likely also had to adjust to no longer being the smartest students. As already noted, most students' changing beliefs about what it means to be smart in engineering expanded beyond traditional metrics of academic achievement (i.e., good grades). It is possible these students experienced the majority of changed beliefs about what it means to be smart in engineering because they were adjusting their beliefs to maintain their own identity as smart in their new academic context of other high academic achievers and match their own efforts and performance to align with their identity as a smart student. Reference [8] found that students can maintain an identity as a smart person through early academic challenges in engineering, and an identity as smart and the idea of smartness as a cultural construct is salient in engineering culture and inextricably connected to engineering identity development [22] .

TABLE VII. CHANGE BY INSTITUTIONAL PATHWAY

Pathway	Students whose Beliefs Changed	
	Number	*Percent*
Honors	5 out of 7	71%
Scholars	4 out of 6	67%
Standard	1 out of 3	33%
Regional Campus	1 out of 5	20%
Community College	1 out of 3	33%
Alternative Math	0 out of 1	0%

V. CONCLUSIONS AND SCHOLARLY SIGNIFICANCE

This investigation continues to build upon research within engineering education that indicates the salient role of smartness in engineering [7]–[9], [23]. Our investigation begins to explore the ways in which students change their beliefs about what it means to be smart in engineering in the early stages of their undergraduate experience. We leverage cognitive dissonance theory as a framework for understanding changing beliefs. We found that most students who experience a notable change in beliefs about what it means to be smart in engineering shift from believing that smartness is measured through achievements like good grades and test scores or an innate ability to shifting to a believe that being smart in engineering means working efficiently.

Experiencing cognitive dissonance and resolving these inconsistencies can be a driving force behind the change of people's beliefs [24]–[26], and we found evidence that the cultural practice of smartness engineering is contributing to students' changing beliefs about what it means to be smart. While change in beliefs about smartness to no longer center grades as the primary indicator of smartness seems like a positive change, there are implications to consider. Participants most often shifted their beliefs about what it means to be smart to emphasize the importance of efficiency. Research on students construction of smartness being related to efficiency in engineering has pointed to several shortcomings: 1) these beliefs introduce ambiguity and ultimately bias into judgements made about who is smart, 2) these beliefs function in ways that maintains a hierarchy based on perceived efficiency, and 3) these beliefs construct smartness as an individual trait instead of recognizing it as a cultural production [7].

Our investigation indicates that these beliefs are being informed by first-year engineering classrooms. Educators need to carefully consider the ways in which our classroom environments and practices not only challenge students' previously held beliefs about what it means to be smart to encourage growth but also inform the development of students' beliefs and understandings of what it means for them and others to be recognized as smart in engineering.

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