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Unpacking Latent Diversity

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Unpacking Latent Diversity

This theory paper explores how diversity apart from social identities like race and gender is framed in the engineering education literature and how these concepts promote a different but compatible approach to understanding diversity—latent diversity. Latent diversity is a new approach to diversity work that captures underlying affective and cognitive differences that provide potential sources for innovation but are not visible. This approach does not examine other non-visible social identities like sexual orientation, first-generation status, socioeconomic status, etc. Prior literature suggests that diversity in approaches, problem solving, and ways of thinking improve innovation in engineering design more reliably than does diversity along the lines of age, race, gender, etc. However, the process of enculturating students into engineering through engineering curriculum often creates homogeneity in students' approaches to problems, ways of thinking, and attitudes. In this paper, I explore a limited set of existing research on diversity from these underlying perspectives including identities, alternative ways of thinking and being, motivation, cognitive diversity, and innovation and creativity. This work synthesizes the findings of these studies to paint a rich picture of how students develop different attitudes and skills to navigate their paths within engineering. Additionally, this work provides an evidence-based argument for the importance of recognizing and understanding latent diversity to promote a more inclusive environment in engineering and recruit, educate, retain, and graduate more innovative and diverse engineers. This paper opens the conversation about a new, but complementary, focus for developing a STEM workforce rich in talent and capable of adapting to the changing STEM landscape.

Introduction

This paper explores some of the current engineering education literature related to affective and cognitive diversity and puts forward a new, but complementary focus for diversity research—latent diversity. Latent diversity is defined as students' attitudes, beliefs, and mindsets not readily visible within the classroom. This approach to characterizing diversity does not examine other non-visible social identities like sexual orientation, first-generation status, socioeconomic status, etc. These non-visible identities are an important topic of research, but latent diversity focuses on underlying student attributes. Many companies are discovering that diverse approaches to problem solutions contribute to product innovation, global competence, and other successful outcomes[1,2]. However, engineering persistently lacks the diverse mindsets and ways of thinking needed to solve complex problems facing our world[3,4].

Much of the research on innovation has operated under a key assumption that external markers of diversity (e.g., age, race, gender expression, etc.) will automatically increase the diversity of solutions. The literature shows inconsistent and mixed findings for this assumption. Some research shows that teams including more variety in diversity indicators like age, race, and gender do not show improved innovation[5,6], while other research has found that minority dissent that actively challenges the basis for decisions can improve innovation[7,8]. This prior research suggests that diversity in ways of approaching problems and thinking differently improves the likelihood of innovative outcomes than traditional diversity measures. As engineering education works to produce engineers through normed practices and curricula, this practice often creates engineers that are more similar than different in their approaches to problem-solving[9,10], ways of thinking[11], and attitudes[12]. This homogenization reduces variability in students' innovation[13] and can create a mismatch between how students perceive engineering as a field and how they perceive themselves as people who engage in engineering, often resulting in a lack of belonging and ultimately, attrition[13–16]. As a result, a gap of understanding how to develop students with diverse and innovative mindsets in engineering education remains.

In a 2014 visit to Purdue University, Paul Eremenko, founding CEO of Airbus Group Silicon Valley technology and business innovation center and former director at Google, stated,

> It strikes me that there are two families or reasons why [we need diversity]…One is social justice. That there should be representation commensurate with the representation of everyone in our society at all levels, including engineering. A different one is that we believe that diversity improves the quality of innovation. But, it is possible that those aren't congruent - that there are groups that we want represented for social justice reasons that have nothing to do with the quality of innovation or those outcomes. It's entirely possible, right? But, I don't have data either way…I think you might do different things depending on which of those are the end game or purpose. So particularly if you care about ideas, the focus, it strikes me, should be on output-centric measures…The way that we segment for diversity, gender, race, etc., the traditional ways of segmenting, are not the right ways to do it [understand diversity in engineering].[17]

Eremenko highlighted two approaches to understanding diversity in engineering. One is focused on who has access to engineering or the input-centric measures related student demographics and social justice issues of access and equity in engineering. The other focus he described was "output-centric measures" of students' attitudes and ways of thinking that promote creativity and innovation in engineering solutions. This paper puts forward and describes a new way of thinking about the attitudes and mindsets in engineering that could affect output-centric measures, latent diversity. This alternative, but aligned approach, could provide another way to understand and support diverse students in engineering. In putting forward this approach, I do not want to undermine or diminish the valuable and important work of making engineering more inclusive and representative of the population. It is imperative that we acknowledge and challenge the social structures that continue to promote inequity, reduced access, and bias in our education system. I do not see this approach as a replacement for excellent prior work or research focused on intersecting social identities. Rather, I see this approach as a complementary way to understand diversity in engineering education research. Below, I describe latent diversity and how this approach can support traditional diversity research in understanding how to recruit, retain, and support diverse students in engineering.

Unpacking Latent Diversity

The concept of latent diversity focuses on the alternative mindsets and experiences that students bring with them into an engineering degree program rather than on their demographics. In doing so, it takes an asset-based approach rather than focusing on the deficits of students on which some research in diversity has focused (e.g., deficiencies in academic preparation, less understanding of high education systems, lack of support systems, etc.). Students, regardless of background, bring diverse and unique ways of thinking and ideas to the table. If engineering culture privileges particular ways of thinking or being as what it means to be an engineer, it may be alienating for latently diverse students. Recognizing students' attitudes, mindsets, and innovation as important provides a way to support all students in engineering.

To date, much of the quantitative research on diversity in engineering education has first binned students by demographic categories and only then examined differences in students' attitudes or beliefs. Several problems commonly exist with quantitative approaches to understanding and supporting diversity[18]. First, students at the intersections of multiple underrepresented categories are small in number. These small numbers can result in several problems that dismiss the importance of these students in engineering. Small numbers of students can be viewed as "anomalies" not representative of the whole and dismissed. Additionally, statistical power to detect differences or understand students at multiple intersections is impossible to obtain in smaller datasets. Finally, these small numbers of students can be disaggregated from the larger dataset in ways that re-identify participants and make their responses non-anonymous, which have ethical implications. The second issue in quantitative research on diversity is that most statistical techniques rely on averages to compare groups or minimize the error of models for the entire population. This approach can result in findings that generalize findings for fixed demographic categories. Many of these studies make claims for all women or all women of color and lose the nuance of individual's experiences. These issues limit the ability of binning individuals by researcher-defined categories to understand how diverse students navigate engineering.

Qualitative research provides a solution to many of these issues including rich and thick descriptions of students' individual experiences that can be used as powerful examples. These "small N" studies[18] challenge the status quo of what it means to do "rigorous" research as well as provide counter narratives to the dominant story in engineering. However, qualitative approaches are also problematic in other ways. There are many potential pitfalls in collecting rich data including significant time for analysis, accurately representing students' narratives and words in ways that remain true to their experiences, and the use of these studies in large-scale reform. There are useful frameworks for ensuring quality in qualitative research[19] that help mitigate many of these issues and provide powerful research and findings of even one individual[20,21].

At times, researchers may feel that the tradeoffs between quantitative and qualitative paradigms result in approaches are incompatible and potentially at odds with one another[22]. This issue caused me to ask the question, "What if there was an approach that could leverage the strengths of large-scale, generalizable quantitative research while also maintaining unique individual characteristics and refraining from making sweeping statements about entire groups of people?" To answer this question, I put forward one potential way to approach characterizing diversity in engineering students by focusing not on outward or non-visible social groups but students' underlying attitudes, beliefs, and mindsets and then examine how demographic backgrounds might be an underlying cause for the manifested attitudes and beliefs. Felder and Brent[23] emphasize the need for this kind of understanding to support engineering students, "Students have different levels of motivation, different attitudes about teaching and learning, and different responses to classroom environments and instructional practices. The more thoroughly instructors understand the differences, the better chance they have of meeting the diverse learning needs of all of their students" (p. 1).

Latent diversity can provide a different way of examining how diverse students navigate their paths in engineering. It also provides a different approach for both qualitative and quantitative research that may address particular concerns about the "small N" while also allowing for both quantitative, qualitative, and mixed methods approaches. This approach does not overcome all of the issues of choosing between research paradigms, but it provides a way to begin to address the concerns raised by the engineering education community. Latent diversity as a distinguishing characterization can help address the power issues in quantitative studies to understand students' diversity by focusing on the outputs of students' attitudes and beliefs that are directly impacted by their background rather than binning students into demographic (and often mutually exclusive) groups. This approach can also support qualitative research that captures rich and detailed nuance of individual differences and aids in understanding a wide range of student' attitudes, beliefs, and mindsets. Latent diversity allows for the variation of the individual along multiple affective and cognitive dimensions, protects against potential re-identification within the data, moves away from dismissing small samples as an anomaly, and refrains from essentializing diverse groups of individuals. This conceptual approach to understanding diversity in engineering education is not a panacea for all methodological issues. Rather, this approach provides a new way of examining multiple affective and cognitive dimensions at once to understand how the individual more holistically experiences and navigates pathways in engineering.

Figure 1 represents how researchers can approach diversity research from a more traditional approach or from a latent diversity approach. This representation shows the research as looking through different lenses in how researchers sample, approach, and analyze data. In traditional diversity research, students are selected for participation based on demographic markers of diversity and then surveyed, observed, interviewed, etc. about their experiences in or attitudes about engineering. This approach can provide insight into how groups of students or particular students experience engineering but still filters the data first by demographic identification. A latent diversity approach first characterizes students' attitudes, beliefs, and mindsets and then examines how students' backgrounds and demographics influenced these diverse affects.

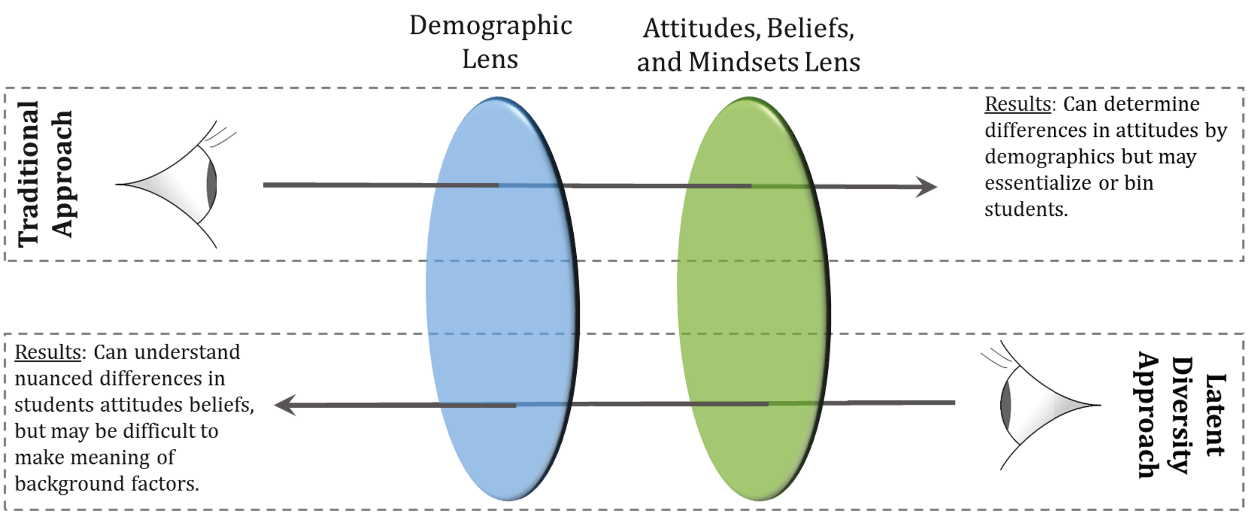

Figure 1. Conceptualization of latent diversity approach and traditional approach. These complementary approaches have unique limitations and strengths and result in tradeoffs that must be considered by engineering education researchers.

Relevant Literature

Numerous studies in engineering education have explored aspects of students' attitudes, beliefs, and mindsets. However, few have examined these aspects in concert and most studies do not make connections to other related aspects of a students' affective and cognitive diversity. This landscape offers an in-depth, but limited understanding of students' underlying diversity in their attitudes, beliefs, and mindsets and how these might contribute to student pathways, success, fit, and the culture of engineering.

Students' attitudes, beliefs, and mindsets are present in the classroom, but are not visible or actualized in student learning; however, these latent attributes have the capacity develop into opportunities for innovation in the future. Students may or may not be aware that they possess these attributes, and educators cannot readily detect them. Understanding how to actualize these alternative ways of thinking and innovative mindsets in students' engineering identity development is key to creating engineers that fit with the National Academy of Engineering's vision for the Engineer of 2020[4] and developing diversity in thoughts and innovation. A recent focus in engineering education on cognitive diversity has highlighted some aspects of latent diversity[24–29] (e.g., ways of thinking and problem solving) but not others (e.g., motivation or epistemology).

In the following sections, I explore the some of the current engineering education literature around particular theoretical constructs commonly used to understand how students navigate their engineering pathways. I focus on a starting set of attitudes, mindsets, and beliefs that are widely researched and often used in understanding diverse students' pathways from a demographic standpoint. This starting set of attitudes, beliefs, and mindsets can help provide an opening conversation for how these attributes manifest in our current engineering population and how these underlying characteristics are influenced by students' prior experiences. This review is not systematic or exhaustive. Instead, I provide a brief general overview of a limited set of trends, findings, and approaches to understanding students' affective (i.e., attitudes and beliefs) and cognitive diversity (i.e., mindsets and approaches) in engineering education. Then, I discuss how the output-centric measures of innovation and creativity have been examined in engineering education. These output-centric measures were chosen based on common argumentation used in engineering education for why diversity is needed—greater diversity will provide more innovation or creativity in engineering solutions[3,23,30–32].

Limited Support for Diverse Mindsets in Engineering Culture

Much of the research to date has focused on how underrepresented students form STEM identities and develop strategies to fit into engineering as a role and culture. However, some studies show that students who think differently, rather than look differently, than the STEM majority tend to struggle in STEM fields. Few studies have examined how these different ways of thinking are developed, but some research shows a higher prevalence of different and innovative thinking exist for traditionally underrepresented students. For example, Boaler and Greeno[33] found that students who saw themselves as creative thinkers and identified with this characteristic tended to have lower interest in traditionally taught math classes. They perceived these traditionally taught classes to inhibit their own thinking and agency. These students had higher levels of satisfaction in reformed math courses where students worked together to solve math problems. In contrast, students who identified as good rule-followers had the opposite experience in a reform-oriented classroom. In another study, "Inez," a student who wished she "belonged more in this whole engineering thing," illustrated the disenfranchising experiences of particular students with alternative ways of thinking[20]. She felt alienated by the traditional pedagogies taught in her engineering and science classrooms like problem-solving algorithms and balancing chemical equations but did well and generally enjoyed using hands-on skills and reasoning through problems in the classroom (practices that many would argue are more representative of successful engineering skills). While this student succeeded in the end, her pathway through engineering could have been easier. Her story may be similar to other students who do not make it through the gauntlet of engineering, and, instead, find fulfillment outside of engineering.

Affective Diversity: Attitudes and Beliefs

Identity. Students often feel like they are becoming engineers but are not one yet. Often engineering culture fosters a sense that there is some pre-requisite amount of knowledge or experience that must be gained in order to be an engineer[34,35]. Identifying as an engineer or scientist matters for students' academic and personal development[36–38], retention[20,34,39], and professional formation[40–42]. The authoring of their stories as engineers or scientists is the central process of envisioning themselves in those roles. In this authoring process, students must negotiate how their individual identities map to the group identity of an engineer or scientist. Development of a social identity within a group requires legitimate participation and recognition within that social sphere[43]. This practice may be exclusionary to students who hold non-dominant identities, mindsets, or attitudes. Students who do not see themselves as coders, nerds, or designers, but as other identities that "break" engineering or science stereotypes may be discouraged from forming alternative identities in STEM that fit with how they see themselves[44,45]. Because of the homogenization of engineers and scientists through a standardized approach to convey canonical knowledge and replication of historical forms of teaching (i.e., lecturing, rigorous testing, etc.) in education[46], a common socialization process into STEM culture has emerged[10]. According to Perlow and Bailyn[47], "a picture has emerged of the 'generic' engineer, the 'generic' engineering job, and the 'generic' engineering career" (p. 231). Arguably, engineering education has focused on equipping students with "generic" engineering skills rather than developing innovative mindsets and alternative identities. Other engineering students also face similar challenges to what is accepted as the "norm" in their disciplines. This lack of identity formation can lead to attrition of the very students who possess unique ideas and ways of thinking which results in the loss of talent[14,15]. This homogenization further reduces the latent diversity of students who stay in engineering, propagating the dearth of talent in engineering industry[3]. Students who do choose engineering, despite these barriers, still face the issue of developing identities in engineering culture that may not fit with their self-ascribed identities and mindsets which may cause many to leave later on after obtaining an engineering degree[48,49], further exaggerating this negative feedback loop.

Ways of knowing. An extensive body of research shows that students' personal epistemologies—how they think about the nature of knowledge and knowing[50]—affect how they approach learning in science, mathematics, and engineering[51–56]. In an engineering education context, epistemology addresses the questions of how we come to know engineering, what engineering learning is, and what constitutes engineering thinking. Epistemology has been measured in domain-general (e.g., what is knowledge and how do we learn?)[57] and domain-specific ways (e.g., what is engineering knowledge and how do we learn engineering?)[58,59].

Carberry, Ohland, and Swan[58] found that first-year engineering students believe that knowledge is relatively unchanging and that engineering knowledge is complex. They hypothesized that these attitudes may originate from traditional STEM learning without opportunity for open-ended problems solving. Other work by Yu and Strobel[59], developed a new instrument for measuring students' beliefs about how engineers know what they know (epistemological beliefs), the reality with which engineering deals (ontological beliefs), and what students believe the discipline and practice of engineering are (epistemic beliefs). These items showed some validity evidence in a pilot study but have not been widely used in engineering education research. More recent research by Faber, Vargas, and Benson[60] adapted Yu and Strobel's instrument and tested it with engineering students for face validity. They found that students' beliefs about problems in the engineering classroom differ from "real-world" problems. Many students discussed that they felt there was one right answer in the classroom, but many answers in a broader engineering context.

A disconnect between how students perceive knowledge and engineering pedagogy can foster a lack of belonging in the STEM classroom. For example, "Michael," a student who valued sense-making over memorization, felt different and isolated from his peers and community[21]. His approach to engineering problems resulted in a deeper understanding, more creative problem-solving strategies, and more innovative solutions—skills that engineering educators desire in *all* students. However, this approach to learning made him an outsider in his engineering classroom. *What about other students with latent diversity, like "Michael" or "Inez?"* Students can feel out of place—they can experience tension between their latent diversity and their roles in particular engineering programs—for epistemological reasons as well as social or cultural identification reasons like gender, race, and ethnicity. Many of these students leave engineering; for those who stay, research suggests "what distinguished the survivors from those who left was the development of particular attitudes or coping strategies"[14] (p. 30). These "particular attitudes" are often more similar than different and limit the potential innovation of engineering solutions.

Motivation. How students see themselves and are positioned by others (i.e., identity) as well as the ways in which they understand and view the world (i.e., epistemology) impact their motivation for particular tasks and goals[61–65]. Student motivation has been widely studied in engineering education. Motivation theory has a rich history in educational psychology, and multiple frameworks have been used to understand the underlying motivations of undergraduate engineering students affect their success, pathways, and actions within their engineering careers. A recent systematic literature review by Brown, Matusovich, McCord, and Kajfez[66] examined the multiple ways that motivation has been used and operationalized in engineering education research from 2009-2012. This study followed Eccles and Wigfield's[67] taxonomy of motivation theories which captures the breadth of motivation in educational research. Eccles and Wigfield grouped theories into four categories 1) expectancy (e.g., belief about the difficulty of a task and a person's ability to perform it successfully); 2) reasons for engagement; 3) integrating expectancy and value of a task; and 4) integrating motivation and cognition. This systematic review found that over half of the articles found did not have a specified framework for their study. Of the papers that used a framework, three were most prevalent including Bandura's self-efficacy construct[68], Deci and Ryan's self-determination theory[69], and Eccles and Wigfield's expectancy-value theory[70]. Self-efficacy is one's belief in his or her ability to succeed in a specific situation or at a particular task. This belief informs how a person approaches goals. Self-determination theory emphasizes that people's actions are driven by external systems (e.g., grades, incentives, rewards, etc.) as well as internal factors (e.g., curiosity, self-satisfaction, interest, etc.). The theory consists of three basic psychological needs to foster positive experience and well-being—autonomy, relatedness, and competence. Autonomy is an individual's ability to be empowered to act of free will in a way that is consistent with his or her interests and values. Relatedness is a desire to interact or connect with others. Competence is the desire to control or master an outcome. Expectancy-value theory focuses on understanding how one's beliefs about his or her ability to succeed (i.e., expectancy) interacts with his or her desire or appraisal of the outcome (i.e., value). These three theories are interconnected theoretically, but little motivation work combines them into a cohesive representation or measurement of motivation.

Other work by Benson and Kirn[71,72] has found connections between how students solve problems in their engineering classes and their long-term goals in engineering. Students who connect course-related tasks to their future goals and value these for their career trajectories (e.g., have high connectedness[73] and clear perceptions of the future[74]) are more likely to persist on challenging problem-solving tasks and work to understand the material rather than cram and forget the material[75].

Matusovich, Streveler, and Miller[37] investigated how students' motivations are tied to their choices of becoming engineers (i.e., identity). They found that interest alone was not sufficient in understanding how engineering students persist in their degree pathways. They emphasized the need for a multi-dimensional way of understanding value including interest, attainment (e.g., importance for self), utility (e.g., usefulness), and cost (e.g., loss of time, high demand of effort, loss of alternative, etc.). The work also called for engineering education researchers to support engineering student motivation by helping students connect their personal identities to engineering identities. This research connected the importance of understanding not only motivation but also identity for engineering students and how they might be connected.

Aligning pedagogy and practices with a diverse set of engineering motivation can support latently diverse students. Engineering has a specific set of cultural values and priorities[76,77]. Students enter engineering with their own diverse motivation priorities that may or may not match the engineering values[37,78,79]. Students who have matching motivations are likely to be supported and furthered in the construction of future-oriented motivations[71]. Additionally, if students are able to connect their current engineering work to future goals, they are more satisfied in their engineering pathways[71]. However, students who do not experience congruence are required to suppress their existing motivations or develop new ones that match the cultural rewards[61]. If students with diverse motivational profiles do not see how their current engineering work or values within an engineering classroom lead to their future goals, they may experience a disconnect in their engineering pathway and be less likely to remain in engineering[15].

Cognitive Diversity: Mindsets and Approaches

Cognitive diversity is a more recent term in the engineering education literature. However, much of the concepts have been researched under other titles for a number of years including personality.

A recent ASEE conference proceeding by Jablokow, Vercellone-Smith, and Richmond[80] explored this topic through Adaptation-Innovation theory. This approach identified four constructs including cognitive level (capacity/resource), cognitive style (preferred approach), motive (driving force), and opportunity (including one's perception of it). These ideas significantly overlap with other ideas explored in this paper including motivation but were focused specifically on problem solving. The cognitive style dimension is the unique aspect of this work from other theories and is contextualized to engineering students through the other three dimensions.

Cognitive style is the amount of structure a student prefers when solving problems with adaptive students preferring more structure and Innovative preferring less structure. Students' preferences, as well as instructor preferences, can influence the environment and emphasis of learning in engineering problem solving. A more adaptive instructor might focus on the details of the process of solving problems while the innovative instructor might value unique or non-traditional approaches. These differences can affect students' abilities to see themselves in the role of an engineering and capable of doing engineering work. Preferences toward problem solving are well set early on[81,82] and may be tied to genetics[83]. Students can adapt their problems solving approaches, but operating outside of preferred working styles can take a toll on learning and affect in the classroom. Additionally, data show that students vary widely in their preferences for solving problems.

Other research has framed cognitive diversity as a way to understand neurodiversity of students with dyslexia[84] or ADHD[85]. These studies frame what are traditionally defined as learning disabilities as opportunities for divergent ways of thinking to promote innovation in engineering problem solving. Fitzpatrick[84] described four major themes from her work that affected students with dyslexia differently than other engineering students. Her interviews revealed that alignment, ideal education environments, dissociation, and time as the major themes that students discussed in relation to their engineering experiences. Alignment captured students' particular skills that originated from their dyslexia that were valued in engineering including awareness of others, ability to communicate, holistic thinking, leadership, and academic achievement. Students also discussed the ideal educational environment around content delivery and user-empowered choices. Dissociation described students' experiences where they felt disconnected from engineering because of their dyslexia—the diagnosis of having a learning disability or language-based challenges. Finally, students' time was a major factor in their engineering experiences related to accommodations, processing speed, and work ethic. Other research has shown that students with non-traditional ways of thinking including ADHD have significant creative potential[86–89]. This research emphasizes the need to understand the challenges and capacity of students with cognitive diversity to promote different ways of conceptualizing diversity more broadly to provide new ways to education engineers of the future and provide a more prepared, creative, and diverse engineering practice.

In summary, multiple aspects of students' attitudes, beliefs, and mindsets are important for understanding how students navigate their pathways in engineering. Research has demonstrated that students' identities, epistemologies, motivations, and aspects of cognitive diversity can inform how students become engineers or leave the engineering discipline. Additionally, these underlying aspects of students' latent diversity are interconnected and vital to understand in the types of students with particular ways of thinking that graduate with engineering degrees. If the process of becoming an engineer in our current engineering education system only rewards particular types of students, we may limit the kinds of diverse thinking needed for the long-term success of the engineering profession including innovation and creativity.

Output-Centric Measures: Innovation and Creativity

Innovation and creativity are highly valued in our constantly changing economy. These characteristics are especially emphasized in engineering design contexts[90], typically in the first-year and capstone engineering experiences[91]. In some work, innovativeness and creativity have been described as a general personality trait that defines a particular position to accept new ideas[92]. Other research posits that creativity and innovation are domain or disciplinary characteristics and cannot be measured in a general form[93]. Innovation has been defined as the introduction or application of a product, process, or procedure that is designed to produce a better outcome that the current one[94]. Creativity had been defined as "tendency to generate or recognize ideas, alternatives, or possibilities that may be useful in solving problems, communicating with others, and entertaining ourselves and others"[95] (p. 396). Research on creativity has most often been focused on K-12 education, whereas research on innovation has most often focused on the workplace[96]. A growing interest in measuring and understanding innovation for engineering solutions has shifted the research agenda and more research is being conducted on ways to understand and measure innovation and creativity for engineering students. "Innovation" and "creativity" tend to be very general terms that mean very different things in different contexts. This section highlights a few of the ways in which these concepts are measured and understood in engineering education. It is not a full review of all the ways in which these ideas are defined or constructed across contexts like design, entrepreneurship, and the intersection of liberal arts with engineering education. For a more thorough review, Ferguson and colleagues[97] describe how innovation has been historically defined and measured in engineering education.

Menold and colleagues[96] conducted a thorough review of how researchers were measuring innovation and creativity across domain-general and domain-specific contexts. They found that there is not a clear or comprehensive instrument to measure engineering innovativeness even though some instruments with validity evidence exist. Domain-specific instruments with strong validity evidence are readily available. However, they do not measure the specific traits, skills, and knowledge that engineers need to be an innovator within a disciplinary context.

Some research has found that a propensity for innovative problem solving as a positive relationship with engineering students' persistence[98]. Research focused on engineering students' creativity and innovation indicates that the two are not the same concept. Creativity is a precursor but not complete requirement for innovative thinking leading to innovation in engineering[99]. Innovation is a key skill in engineering that continues to be a focus of research but does not have a consistent or valid way of measuring it. Understanding how students' propensity for creativity promotes innovation in engineering can help develop engineers prepared to solve the complex global challenges facing engineering education.

Other work has demonstrated mixed results of engineering students' innovation over time in their education. Some studies illustrated that senior engineering students were more likely to consider multiple options and consequences of choices before committing to a particular design solution[100–

[102]. In contrast, other studies find the opposite result that freshman students are better prepared to solve ill-defined problems and develop more innovative solutions[103,104]. These findings raise the question of how engineering education is shaping students' abilities to tackle complex problems and if engineering is stifling rather than encouraging particular output-centric measures essential for engineering[9–13,17].

Combining Multiple Perspectives to See a Bigger Picture

Some readers may be familiar with the story of the blind man and an elephant. This story is believed to originate in the Indian subcontinent and has been widely adapted and retold across multiple religious traditions including Jainism, Buddhism, Sufism, Hinduism, and Bahá'í. The story was popularized by the American poet John Godfrey Saxe when he retold the story in 1865[105]. A Chinese version of the folk tale is reproduced below[106]:

> One day, three blind men happened to meet each other and gossiped a long time about many things. Suddenly one of them recalled, "I heard that an elephant is a queer animal. Too bad we're blind and can't see it."
>
> "Ah, yes, truly too bad we don't have the good fortune to see the strange animal," another one sighed.
>
> The third one, quite annoyed, joined in and said, "See? Forget it! Just to feel it would be great."
>
> "Well, that's true. If only there were some way of touching the elephant, we'd be able to know," they all agreed.
>
> It so happened that a merchant with a herd of elephants was passing, and overheard their conversation. "You fellows, do you really want to feel an elephant? Then follow me; I will show you," he said.
>
> The three men were surprised and happy. Taking one another's hand, they quickly formed a line and followed while the merchant led the way. Each one began to contemplate how he would feel the animal and tried to figure how he would form an image.
>
> After reaching their destination, the merchant asked them to sit on the ground to wait. In a few minutes, he led the first blind man to feel the elephant. With outstretched hand, he touched first the left foreleg and then the right. After that, he felt the two legs from the top to the bottom, and with a beaming face, turned to say, "So, the queer animal is just like that." Then he slowly returned to the group.
>
> Thereupon the second blind man was led to the rear of the elephant. He touched the tail which wagged a few times, and he exclaimed with satisfaction, "Ha! Truly a queer animal! Truly odd! I know now. I know." He hurriedly stepped aside.
>
> The third blind man's turn came, and he touched the elephant's trunk which moved back and forth turning and twisting and he thought, "That's it! I've learned."
>
> The three blind men thanked the merchant and went their way. Each one was secretly excited over the experience and had a lot to say, yet all walked rapidly without saying a word.

> “Let's sit down and have a discussion about this queer animal,” the second blind man said, breaking the silence.
>
> “A very good idea. Very good.” the other two agreed for they also had this in mind.
>
> Without waiting for anyone to be properly seated, the second one blurted out, “This queer animal is like our straw fans swinging back and forth to give us a breeze. However, it's not so big or well made. The main portion is rather wispy.”
>
> “No, no!” the first blind man shouted in disagreement. “This queer animal resembles two big trees without any branches.”
>
> “You're both wrong.” the third man replied. “This queer animal is similar to a snake; it’s long and round, and very strong.”
>
> How they argued! Each one insisted that he alone was correct. Of course, there was no conclusion for not one had thoroughly examined the whole elephant. How can anyone describe the whole until he has learned the total of the parts?

The message of this tale can also be applied to our understanding of students’ attitudes, beliefs, and mindsets in engineering education. Excellent research has been conducted across different foci and theoretical frameworks as summarized in this paper. Engineering education research has examined different aspects of students’ attitudes, beliefs, and mindsets to deepen our understanding of how these underlying characteristics influence particular outcomes of engineering students. However, many of these research traditions are not connected and the “big picture” of engineering students’ mindsets and attitudes has not been fully explored. Individually, these research foci give a partial, but incomplete picture of how diverse students navigate their pathways in engineering. Latent diversity combines these multiple perspectives to understand holistically students’ multiple and layered attitudes as well as how these underlying characteristics affect how they negotiate their identity as an engineer. This approach also includes how latent diversity is shaped by students’ experiences, and thus, latent diversity integrates intersecting social identities like race or ethnicity, class, and gender as well as others.

A Complementary Focus

Examining ***latent diversity*** or diverse students’ mindsets, thoughts, attitudes, and potential for innovation offers one way to delve deeper into the underlying characteristics of student diversity. These latent attributes are present, but are not visible or actualized, and have the capacity to become or develop into opportunities for innovation in the future. Students may or may not be aware that they possess these attributes, and educators cannot readily detect them. Students enter undergraduate education with a variety of backgrounds, affective beliefs, and mindsets that are often developed in becoming “an engineer.” Our current educational practices develop students with more similar mindsets than different which is problematic for innovation[9–12]. Also, this process alienates many students[14], and engineering professions lose innovation and talent if these latently diverse students leave. Recognizing and understanding this form of diversity can promote a more inclusive environment in engineering and recruit, educate, retain, and graduate more innovative and diverse engineering professionals.

This innovative perspective significantly expands traditional definitions of diversity to understand how individual student differences affects students’ engineering identities and feelings of belonging within engineering. The outcomes of research with this alternative approach to understanding diversity can provide new ways of understanding how to support and foster alternative mindsets within engineering to promote innovation. I recognize that there is some risk in focusing on latent diversity to create excuses for ignoring visible diversity (e.g., women and people of color). This perspective is not a replacement for excellent prior research in ways to support underrepresented students in engineering, but a compatible strand. I believe that making the culture of engineering more inclusive will not only benefit the majority, white men, but also a broad spectrum of talented students that may not see engineering as a viable option or may choose to leave engineering in college. Latent diversity offers a novel way to conceptualize diversity research and provides complementary ways of understanding how innovation through diverse perspectives can be developed and supported in engineering.

Future Work

This paper is a first exploration of the idea of latent diversity to start a conversation in the engineering education community. The purpose of this paper was to lay the groundwork for thinking about and researching underlying or latent aspects of diversity in engineering students. This paper also makes the argument that separate research across domains of students' attitudes, beliefs, and mindsets need to be understood together rather than separately to see a more comprehensive picture of the types of students entering and exiting engineering education. The theories and research included in this paper provide a starting point for future work in understanding how latent diversity is present in engineering students and how it influences diverse students' pathways into and out of engineering. In future work, I plan to identify systematically particular aspects of latent diversity that are most important to understanding student success and challenges in engineering through a national survey of first-year engineering students and longitudinal qualitative data collection.

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