Engineering Learning among Black and Latinx/e/a/o Students: Considering Language and Culture to Reengineer Learning Environments

Dr. Greses Perez, Tufts University

Greses Pérez is the McDonnell Family Assistant Professor in Engineering Education in the Civil and Environmental Engineering Department at Tufts University with secondary appointments in Mechanical Engineering and Education. She received her Ph.D. in Learning Sciences and Technology Design with a focus on Engineering Education from Stanford University. As an Afro-Latina engineer and learning scientist, she has dedicated her career to investigating the experiences of Latina/o/x and Black students in engineering.

Her scholarship is particularly focused on the relationship between the language and cultural practices of communities and engineering practices. Through her research, teaching, service and mentoring, she supports traditionally underrepresented students who experience a cultural mismatch between the ways of knowing and speaking in their communities and those in engineering. In addition to her work on culturally relevant learning through emerging technologies, Greses uses mixed methodologies to investigate the strengths multicompetent individuals, whose lives exist between languages and/or cultures, might be able to contribute to the social fabric. Her mission is to expand who is heard and can contribute to the disciplines as society demands professionals with backgrounds as diverse as the challenges we face.

Greses' scholarship advocates to include the rich trove of insights from multicompetent groups in creating engineering solutions and scientific ideas. Before her time at Stanford, she was a bilingual educator at low-income elementary schools in Texas. As a civil engineer, Greses led EU funded projects in the Caribbean to create educational opportunities for coffee farmers and their families. She also holds two Master's Degrees in Civil and Environmental Engineering from the University of Puerto Rico at Mayagüez and in Education Policy & Leadership from Southern Methodist University, as well as a Bachelor's Degree in Civil Engineering from the Instituto Tecnológico de Santo Domingo.

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Clara Mabour is a first year STEM Education Ph.D currently researching hip hop as a culturally sustaining method for teaching STEM. She has a bachelor's in environmental science from the University of Florida. Prior to starting her studies at Tufts, Clara taught high school science and research and she ran STEM and invention focused afterschool programs and summer camps in South Florida. Her experience as a Haitian immigrant in South Florida have shaped her teaching approaches research interests. Clara's research interests focus on the intersection of culture, learner agency, materials, and problem solving in informal and formal K-12 STEM learning spaces.

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Marvez is a PhD student in the joint STEM Education and Cognitive Sciences program at Tufts University interested in games, language, and controversial discussions. In past research projects, they have worked on the development of virtual simulations for teachers to practice leading controversial discussions. They are interested in ways to prepare teachers to facilitate controversial debates with students in STEM classrooms, such as through simulations and games, on topics such as genetic modification, climate change, and public infrastructure. Marvez has also worked on the development of natural language processing models for assessment and personalized feedback in educational settings. At Tufts, Marvez works with McDonnell Family Assistant Professor Greses Pérez in the CEEO on the development of engineering board games for multilingual students in culturally relevant contexts.

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Currently, Ymbar is conducting research for the National Renewable Energy Laboratory (NREL) and the Department of Energy (DOE), alongside Andrew Parker and Dr. Greses Pérez, to enable equity considerations in commercial building energy efficiency programs through data analysis and community engagement. He hopes to continue doing research that supports and creatively engages historically excluded communities within the renewable energy transition. Ymbar is interested in using media and the arts as community-preferred learning approaches to demystify complex scientific concepts, rendering them more accessible, relatable, and engaging. This approach not only enhances community engagement and participation in energy justice initiatives but also contributes to a more inclusive and equitable educational landscape.

Ymbar is a research assistant for Dr. Greses Pérez, Tufts University Professor in Engineering Education, Mechanical Engineering, and Civil and Environmental Engineering.

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Abstract

This conceptual paper explores language and cultural resources as forms of multicompetence for engaging in engineering epistemologies (what we know) and practices (what we do). The need for a more diverse pool of engineers to tackle the complex challenges facing society is undeniable, but stereotypes about the discipline can create alienation among many students and undermine efforts to build a more inclusive profession. Drawing on scholarship from engineering education, science education, and learning sciences, this paper argues that the resources of Multicompetent Learners (ML), who have acquired valuable experiences and knowledge through social interaction within their communities, are valuable for engineering learning environments. By leveraging the language and cultural resources that students bring with them, engineering education can better prepare learners to develop solutions and knowledge that serve a diverse population. This work underscores the critical role of language and cultural resources in helping students be heard, seen, and understood in engineering and illustrate how these resources can help bridge the gap between students' lives and engineering. The paper further explores the multidimensional nature of language and cultural resources and how students draw on different sets of talk depending on the context, whether near or distal from the activity at hand. It contends that without a deeper understanding of the role of non-dominant ways of speaking in the act of becoming and belonging, efforts to diversify engineering will remain elusive. Ultimately, this paper summarizes these ideas through a conceptual model for engineering learning environments that value and leverage the resources that students bring from their communities. By creating more equitable and socially just solutions, engineering education can better serve the needs of diverse populations and ensure that the profession is truly reflective of the communities it serves.

Keywords: language and culture; engineering learning; Black and Latina/o/x communities; equity; engineering justice; multicompetence

Engineering learning among Black and Latine students: Considering Language and Culture to Reengineer Learning Environments

Lorena is a senior in civil and environmental engineering at a private elite institution. As a first-generation low-income college student from a border town in California, she grew up with a vague idea of engineering. Lorena decided to major in engineering because she was top of her class in STEM related subjects. Her community was predominantly transnational and translingual (Spanish, Spanglish, English, and indigenous languages). In her community, people learn at an early age the value of tinkering, upcycling, and fixing objects using the resources in their surroundings. She graduated top of her class in a school with a predominantly Latine population. The story is different in college where she is often the only Latine student in her classes. There, she hides the competencies learned in her community as they do not look as cutting edge as the robotics and design examples in the models of engineering portfolios. Her ideas are powerful yet frequently misunderstood by her peers, most of whom grew up in affluent communities. During her last engineering design project, her team dismissed her ideas about how to design a low-cost but durable automatic seed plotter – despite her insider knowledge as a member of a farming community in the Central Valley. As a member of the community, Lorena understands the needs of her community, which is useful in understanding how to develop a better design for people. In fact, Lorena's grandfather had used the knowledge of his Black Mexican ancestors to create a homemade version of the seed plotter that Lorena helped him build and others in the community replicated their design. There was one experience that had a dramatically different impact on Lorena:

> *The only time others saw me as an engineer and I could be myself was when I worked with an Afro-Boricua community near the school. The community spoke Spanish. I understood the people better than anyone else in my team. Suddenly, I had a voice as an engineer. I was valued and seen.*

Social justice and equity in engineering education

Calls for equity and justice in engineering education have primarily focused on efforts to diversify the 'engineering pipeline' with limited results in broadening participation of engineers of color and other minoritized groups in the discipline. The problematic logic of the 'engineering pipeline' mistakenly assumes that attracting more people of color in engineering is the solution. It also assumes that students' ticket to a better life is to leave behind their communities in search of a better future, detach from the same people who look like them, an idea that can further alienate these students from a career in engineering [1]. The issue transcends the mere inclusion of Black and Latine communities in the discussion of what equitable and socially just engineering entails. It demands a shift towards Black and Latine communities leading engineering ways of doing and the processes of developing technologies and solutions. Moreover, these transformations demand that the discipline sees community resources in their own right, as legitimate forms of knowledge and practices in engineering, without expecting the acculturation of Black and Latine/x/a/o students.

Another dimension of equity and justice efforts in engineering education focuses on disciplinary context and content, particularly what epistemologies and ontologies are valued in the discipline. Scholars and policy makers have called for sociotechnical approaches that give a humanistic and community-centered perspective to engineering [2]-[4]. During her tenure leading the Office of Science and Technology Policy (OSTP), Nelson [5] contributed to this idea by arguing for establishing meaningful connections between our technical, scientific and social worlds, advocating for a science and engineering that is more reflective of the communities it serves. This message was a plea for incorporating the voices and experiences of Black and Brown people, and other historically underrepresented groups, who have been affected by and alienated from science and engineering enterprises.

In characterizing the problem, both scholars and policymakers call for an equitable and socially just engineering providing recommendations for inclusive and anti-discriminatory pedagogical approaches. These suggestions range from capitalistic arguments of increasing the participation of traditionally underrepresented groups in engineering with the goal to reduce the engineering workforce shortage or fostering the cultural competency of practicing engineers for the sake of profit increase [6], [7]. However, there are limitations in how these suggestions have been implemented, as they have not resulted in the changes that underrepresented groups feel need to occur. Perhaps because such recommendations have focused on looking at underrepresentation as the result of less people entering engineering without further investigating the causes. This logic reflects limited attention to systemic issues around how engineers are trained, stereotypes about who engineers are and what they do, and perceptions of the discipline itself. In response, equity and justice-oriented scholars have suggested to deconstruct and reimagine social realities by elevating learning that is inclusive of the funds of knowledge from students and their communities and includes the social and technical realities of society in the curriculum, thus expanding pathways into engineering education and the profession [8] – [11]. Others have highlighted the importance of considering together the technical and social dimensions of engineering, as opposed to two different systems, describing “social empathy and care as essential aspects of engineering education and practice [12]. These efforts have emerged as prioritized and contextualized views of engineering that account for the broader social, cultural, and political context shaping the discipline [12], [13] – [15]. Table 1 shows a non-exhaustive summary of recommendations and their central focus provided by equity and justice-oriented scholars.

There is a need to understand the challenges and opportunities of incorporating and accounting for social context in engineering learning, especially the realities of groups historically marginalized in engineering, such as Black, Latine and indigenous people. In the past, the problem of expanding what we consider valuable resources in engineering has been limited to preserving the status quo and maintaining the supremacy of dominant frames in the discipline, representing a systemic challenge. Despite the long history of scholarship in teaching practices and frameworks that consider learning as inherently social and cultural [16], the lack of understanding of context for engineering learning remains a roadblock to fulfill the promise of diversifying the discipline. The effective enacting of equitable and socially just engineering initiatives to develop disciplinary discursive practices for all remains unfulfilled. This is particularly crucial for groups which have been historically made invisible in the discipline and who may experience cognitive and linguistic dissonance between what they know to be true in

their local contexts and the realities they experience in educational programs [17]. Factors such as community resources (e.g., knowledge, systems of understanding the world around us, experiences and values, cognitive resources), and in particular language practices, play a key role in mediating learning yet they are still poorly understood in the context of engineering [14], [18], [19].

Table 1. Suggested recommendations for equitable and socially just engineering learning

Focus	Recommendations
Students and communities	• Increasing participation of traditionally underrepresented groups through policy [20]. • Honoring the language(s) and cultural practices of minoritized communities, recognizing how racialized ideologies shape engineering education [21].
Curriculum and students	• Fostering cultural competencies and social justice through culturally responsive engineering curriculum [22], [23]. • Link between social and technical aspects [24] - [26].
Learning	• Learning centered in students' funds of knowledge
Profession and education	• Expanding pathways into engineering
Broader issues, the profession, communities, education	• Contextualizing the work in the social, cultural and political context shaping the discipline • Addressing power and inequality as well as environmental justice through a dimension of care in engineering education [12].

The role of language practices in equitable and socially just engineering learning

To effectively implement agendas for equity and justice in engineering, an expanded understanding of the relationship between the wealth of experiences students bring into the classroom and disciplinary practices is crucial. While engineering education scholarship considers various factors as important for learning, from study techniques to instructional practices [27] – [29], the role that language practices play in learning engineering and becoming an engineer remains generic and often ignored without emphasis on how it provides or hinders opportunities for learning. The topic of language is an important one that provides valuable insight toward improving inclusive and equitable practices in engineering education. However, while scholars recognize the fundamental role of language practices and discourses in disciplinary learning [30] – [35], most of this work has emerged from science education or applied linguistics with little attention to non-dominant languages in the context of engineering, and even less so with a focus on equity and justice.

Understanding the role of language requires moving beyond obtuse conceptualizations of language and learning towards considering the complex matrix of domination and privilege between speakers of different communities. And because of the power dynamics always present in classrooms [36], especially in technical disciplines, which are reflected in broader social interactions, we need to understand the multiple factors individuals ponder when making

language choices in engineering learning environments. Indeed, language plays a key role in both disciplinary learning and in building an associated disciplinary identity (e.g., as a scientist or as an engineer), particularly for Black and Brown students.

The constantly changing nature of engineering education, especially in the current times of social and political reckoning, calls for successful approaches to teaching and learning that position communities' ways of speaking and knowing as central to the training of engineers. The times demand from us to truly embrace the richness (including linguistic heterogeneity) within our differences and move beyond the superficial inclusion of diversity and normative identities [37]. The moment has moved us to honor the strengths all people might be able to contribute to the social fabric. Yet as suggested by Gebru in 2020 when sharing her experiences as a woman of color in tech, many still look at differences – cultural as well as linguistic – through a deficit lens, even within well-intended efforts to diversify engineering. The literature on language resources is discussed in regard to teaching and learning through a critical lens investigating for whom and why certain ways of communicating are legitimized in engineering.

Studying language resources

Resources can be broadly defined as material, symbolic, or social aspects of a space that influence learning and engagement. For instance, resources can be embodied competencies, such as language, cognition, and gestures [39]. Other examples of resources are social norms (rules, laws, instructions, maps), physical spaces (classrooms, schools), spatial conceptions, material objects (technology, chairs), ideologies, and others [39] – [41]. All of these resources channel human behavior and have knowledge embedded in them to the point that humans might make unconscious use of them. This concept has been used widely in the learning sciences and sociolinguistic literature to study affordances in the learning environments or how communities of speakers develop competencies in particular contexts.

In educational settings, resources are arranged through processes of production, which afford or hinder opportunities for learning. A material example of resources at work is the ways chairs in a classroom can be reorganized to regulate human behavior as in a horseshoe seating configuration to promote collaboration. Another example is the way languages in a dual language program are limited to a particular subject or time of the day, such as when engineering is taught only in English and math in Spanish. Therefore, language just like space in a classroom is a recognizable resource for learning that is produced and reorganized. Rampton [42] provides the example of 'language crossing' as a form of resource where speakers "use a language which is not generally thought to 'belong' to the speaker" (p. 291). In this case, individuals have to think about which rules are applied, where do these rules take place, for whom and why. The author describes social and ethnic boundaries that were changed within friendship groups to communicate legitimacy, such as using "creole in multiracial groups and Asian English and Panjabi with members of ethnic outgroups" [42, p. 301]. These students are what Pérez [43] describes as Multicompetent Learners (ML) who inhabit and transgress diverse linguistic and cultural communities and who may engage in organizing their language resources based on social expectations for a particular goal. For instance, some Latine/x/a/o students compartmentalize which languages they use in different contexts; some keep Spanish for home and English for school [44]. Multicompetent Learners engage in such practices as a result of entire socio-political

and academic systems that signal to them what is valued and legitimized in private and public spaces. In the case of engineering and engineering education, the decisions about what resources are organized, in which contexts, for whom and for what purposes affords opportunities for some groups, typically a minority who is closer to a perceived norm, while making them inaccessible for others who do not conform to the standard. Therefore, if in engineering learning these learning resources, including language, are arranged to construct a social reality, they can also be rearranged to change such a reality.

Different factors have been found to influence how individuals draw on their language resources depending on the context. Traditionally, science and engineering education have conceptualized language resources either from a cognitivist or sociocultural perspective. Proponents of the cognitivists perspective argue that people who are immersed in disciplinary learning ought to develop and use specific epistemic and linguistic resources for that discipline [45], [46]. And indeed, most of this work has traditionally pursued cognitivist lenses where knowledge and language are developed for extrinsic reasons with the locus in the individual capacity of the mind. In this view, language is developed in stages of proficiency with the goal of reaching a standard form, making the language practices stereotypically associated with disciplinary knowledge a goal for education. However, making disciplinary practices the focus of education has resulted in ignoring the larger context in which learning happens for diverse populations, while simultaneously reinforcing normative language policies [47], [48]. In engineering education, it has resulted in essentialist approaches, which flatten the differences within interdisciplinary and diverse teams [49]. According to Shamos [50], in these contexts, students are often expected to follow vocabulary progressions, of scientific or technical nature, with the goal to speak like “scientists” or “engineers.”

While cognitivists see the development of scientific and technical knowledge along with discursive practices primarily in response to external motivations, sociocultural scholars emphasize language and disciplinary learning as social and cultural processes within particular communities. Therefore, science and engineering learning entails to legitimize and link to disciplinary knowledge and practices the language resources acquired through social interactions within meaningful settings, such as the communities and spaces where students claim membership [30], [51] - [56]. As such, Multicompetent Learners come to engineering classrooms equipped with valuable communicative resources for disciplinary learning. In combination with features in the learning environments, these language resources support understanding and identity development, providing a space for students to be heard, seen and understood in engineering.

Sociocultural theories make sense of language in tandem with sociocultural understandings, offering a frame for critically evaluating the social constructions of language boundaries in the engineering classrooms. Contrary to the common conception of the existence of a “language of science” or a “language of engineering” [57] – [59] or even the named languages associated with nation-states, such as the U.S. imagine as an English-only nation [60], language is seen as a dynamic and fluid resource within sociocultural theories [61]. Students draw on their language resources from the engineering learning experience at hand while incorporating the social language acquired in meaningful social interactions within their local communities.

The construct language resources, also known in the literature as communicative or linguistic resources or ways of speaking, is not operationalized as referring to interpretation services or multiple modes of communication such as sketches and prototypes. Instead, language is seen as a resource that affords opportunities to learn or serve as gatekeeper for traditionally marginalized groups in engineering. Although research about teaching and learning in diverse settings point to the relevance of language resources for connecting students' lives with engineering, particularly for Black and Latiné communities, the lack of understanding of language as a fluid concept remains a major contributor against efforts to make engineering education accessible for these Multicompetent Learners.

Conceptualizing language as multicompetence

Multicompetence, a term widely used in applied linguistics, involves the language, experiences, values and cognitive resources of learners – individuals who engage in the practices of their communities and the dominant society or those who live between languages and cultures [62], [63] – often referred to in practice and theory in deficits terms but that we want to elevate in this piece. When using terms that quantify and turn language resources in engineering learning environments into discrete entities or others that communicate negative stereotypes of who can become an engineer or who can engage in engineering, such as the term English Language Learners (ELLs), we are restraining the diverse repertoires of these speakers and stifling the pathways into technical careers for culturally and linguistically diverse communities. Terms like ELLs or bilinguals limit the plethora of experiences that the speakers bring by focusing on quantification of languages or their progression instead of considering the wide range of resources they index through language practices (both cognitively and culturally) in engineering learning environments.

Some of the underlying assumptions of the multicompetence framework is that learners are equipped with experiences and values from the different communities where they engage. Moreover, those experiences and values serve important purposes for learning, engagement and belonging. Expanding Cook's notion of multicompetence in language [62], [64], we proposed in this piece that students bring to the engineering learning environments a network of resources (cognitive, language and cultural, to mention a few) resulting from interactions in social communities (e.g., speaking Spanglish and/or Black-Spanish in Latine neighborhoods) without dependency to standard norms of what society values as privileged forms of knowledge and ways of speaking. Students' language resources influence the environment.

In thinking about imagining and creating an equitable and socially just engineering education, this paper proposes that engineering learning environments start seeing the language resources of communities historically made invisible in engineering, such as Black and Latine groups, as a multicompetence [62], [65] that contributes to the production of and engagement in disciplinary knowledge and practices. Although all students bring language resources to the classroom, this work intentionally focuses on the linguistic assets of Black and Latine/x/a/o engineering students whose ways of communicating are often invisible and delegitimize in engineering talk. Without a deep understanding of the role of non-dominant languages in the act of becoming and belonging in engineering, the effective enactment of efforts to diversify the discipline will remain a chimera.

Summary and future work: developing learning environments for studying how incorporating language resources shape students learning, belonging and academic outcomes in engineering education

Engineering education is tasked with training the next generation of individuals who will develop technologies and solutions and who will create the kinds of worlds (both virtual and physical) for a growing diverse population. Calls for change in engineering education continue to ask for diversifying who is in the discipline as well as what counts as valuable technical knowledge. In this framing, the role of what students bring into the classrooms (who they are, what they know and how they communicate their ideas) is an important aspect to ponder if we truly environ a diverse engineering landscape.

This work advocates for expanding engineering, including what we do and how we do it, in learning environments to afford opportunities for each and all learners to use the range dimensions of who they are. It invites society and the discipline to create engineering solutions through the richness of multicompetent communities. In the process of figuring out the problem as well as producing, assessing, and creating new human realities [66] – [68], equity and justice in engineering can begin if we invite differences into the discipline and welcome individuals to come as their whole selves without expecting them to acculturate to dominant ways of speaking. Diverse people bring unique strengths to the table, and their presence changes engineering for the better. The language resources these Multicompetent Learners bring to the classrooms could help us reimagine engineering learning environments where students stay true to themselves and their community values to create equitable and socially just technologies and solutions for all.

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