International Journal of Science Education, Part B
Communication and Public Engagement

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rsed20

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To cite this article: Craig O. Stewart, James T. Campbell, Tony Chase, Maryam Darbeheshti, Katherine Goodman, Seyedehsareh Hashemikamangar, Miriam Howland Cummings, Stephanie S. Ivey, David J. Russomanno & Gregory E. Simon (26 Feb 2023): Communicating identity in the Urban STEM Collaboratory: toward a communication theory of STEM identities, International Journal of Science Education, Part B, DOI: 10.1080/21548455.2023.2179380

To link to this article: https://doi.org/10.1080/21548455.2023.2179380

Published online: 26 Feb 2023.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, PART B
https://doi.org/10.1080/21548455.2023.2179380

Communicating identity in the Urban STEM Collaboratory: toward a communication theory of STEM identities

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ABSTRACT

Although jobs in science, technology, engineering, and math (STEM) fields are projected to grow at twice the rate of other professions, too many students, especially women and minoritized students, choose not to study or drop out of STEM fields, in part because they do not identify with STEM. With Communication Theory of Identity as a sensitizing framework, this study focused on a group of students who are 'at risk' for dropping out of STEM due to unmet financial need who are participating in a scholarship program designed both to close their financial need gap and to build their STEM identities. Based on Interpretive Phenomenological Analysis of 20 semi-structured interviews, the findings show that these students largely, but not exclusively, saw being a 'STEM person' as positive, but also expressed varying degrees of certainty and potential 'identity gaps' about their STEM identities. Enacted and relational STEM identities were of particular importance to how these students understood and experienced STEM identity. Women and minoritized students spoke of the importance of seeing and interacting with STEM people who share their social identities in developing their own STEM identities. Implications for a communication theory of STEM identities are discussed.

ARTICLE HISTORY
Received 14 July 2022
Accepted 7 February 2023

KEYWORDS
Communication theory of identity; interpretive phenomenological analysis; STEM

On the Showtime series *Shameless* (Wells et al., 2011/2021), the character Philip 'Lip' Gallagher is a brilliant student from a poor household who wins a scholarship to fictional Chicago Polytechnic University to study robotics. Despite being extremely intelligent, Lip is unable to fully embody the identity of a robotics major. He has multiple obligations to his family but receives little material or emotional support. To his friends from the neighborhood, he is a 'college boy' who no longer fits in. To his classmates, he is the kid who works in the cafeteria, a 'scholarship kid.' While Lip has more than enough talent to succeed in a STEM (science, technology, engineering, and mathematics) field, all these factors make it difficult for Lip to see himself, and for others to see him, as a future scientist or engineer, and he eventually is dismissed from the university. Although heightened for

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drama on *Shameless*, these sorts of challenges to aspiring STEM majors/professionals are all too common (Roscoe, 2022).

Despite STEM jobs being projected to grow at twice the rate of other professions (Bureau of Labor Statistics [BLS], 2021), too many talented students choose not to study STEM in college or leave these fields before completing their degree, especially women and members of other historically excluded groups. In computer science, engineering, and physics, women receive fewer than a quarter of bachelor's degrees. Blacks/African Americans receive fewer than 10% of STEM degrees outside of psychology and social sciences, and Hispanics/Latinos are similarly underrepresented (National Science Foundation [NSF], 2021). Helping students to build their STEM identities is one important way STEM educators have determined to keep more students, especially women and minoritized students, in the 'pipeline' or on the 'pathway' to STEM degrees or careers (e.g. Doerschuk et al., 2016).

As Roscoe (2022) argues, pipeline and pathway metaphors are problematic, imagining students as non-agentive resources flowing through or being restricted (in the pipeline) or foregrounding the route rather than the individuals traversing it (on the pathway). Therefore, Roscoe suggests the metaphor of 'STEM journeys' to emphasize that 'people travel these pathways with purpose' (p. 4). To center the people on these journeys we take communicative and phenomenological perspectives on STEM identities in the present study. The purpose is to investigate how a group of academically talented STEM students who might be 'at risk' of dropping out of STEM due to financial need subjectively understand and experience their emerging STEM identities. In the following section, we briefly review the literature on developing STEM identities. We then describe the theoretical and analytical frameworks for the present study–the Communication Theory of Identity and Interpretive Phenomenological Analysis. Finally, we describe the applied research context for the study.

Developing STEM identities

STEM identities include identities associated with specific disciplines within the STEM acronym (e.g. science identity, engineering identity). However, while there are potentially important differences between these discipline-specific identities, the boundaries between them are fuzzy and there are substantial overlaps (Simpson & Bouhafa, 2020). For example, engineering identity comprises science (physics) and math identities (Godwin et al., 2016), and students' 'science capital' strongly predicts attitudes across STEM fields (Moote et al., 2020). We therefore use the broader term STEM identity/ies not to elide differences between STEM disciplines but to account for these overlaps and offer a framework that is broadly applicable across STEM identities (Stewart, 2022).

One's STEM identity is the extent to which they are recognized by self and others as a 'STEM person' and comprises three dimensions: competence (one's knowledge and understanding of STEM); performance (one's ability to 'do STEM'), and recognition (the extent to which one is seen by others as a STEM person; Carlone & Johnson, 2007). STEM identities have been studied across grade-levels through adulthood, within different disciplines, and from various theoretical and methodological perspectives (Simpson & Bouhafa, 2020). Students with stronger STEM identities are more likely to choose STEM majors and work in STEM careers; this pattern is especially true for women and members of minoritized groups (Chemers et al., 2011; Chen et al., 2021; Perez et al., 2014; Robinson et al., 2018). However, women and other minoritized students may be less likely to develop strong STEM identities because they may not feel they belong in STEM or experience bias from STEM faculty or peers based on their gender, race, or ethnicity (e.g. Chang et al., 2011; Hazari et al., 2013) and/or their socio-economic, first-generation, or post-traditional (aged 25 or older) status (e.g. Jackson & Seiler, 2017; Wilson & Kittleson, 2013).

As Kim and Sinatra (2018) argue, STEM 'identity develops in relation to and through interactions with others, making identity inherently social in nature. Accordingly, the experiences in science education settings … with peers, teachers, professors, mentors, and materials in those settings, inform individuals' understandings of self' (p. 2). Formal educational interventions, such as bridge programs between high school and college (Kuchynka et al., 2019), experiential field-learning (Goralnik et al., 2018), course-based research experience (Esparza et al., 2020), service-learning (Gubbels & Vitello, 2018), and science communication training (Cameron et al., 2020), have all been associated with stronger STEM identities. Likewise, early informal STEM educational experiences with families, friends, and teachers are associated with stronger STEM identities in college (Dou et al., 2019; Stitt Richardson et al., 2020). In college, informal relationships (Hurtado et al., 2011; Nadelson et al., 2015) and formal mentoring relationships with faculty (Piatt et al., 2020; Robnett et al., 2018) are associated with stronger STEM identities, as is serving as a peer mentor to other students (Huvard et al., 2020) and engaging in other peer interactions (Espinosa, 2011).

Theoretical and analytical framework

Based on a systematic review of over 200 published articles (Simpson & Bouhafa, 2020), the most common approach to studying STEM identities among college students is to consider STEM identities in terms of individual attributes while 'rarely considering how identities are performed and shaped while interacting with others in a particular context' (p. 184). In contrast, we approach the study of STEM identities using the Communication Theory of Identity (CTI) as a lens (Hecht, 1993; Stewart, 2022). CTI sees identity as a multi-layered, communication process, implicating four interpenetrating frames or layers (Jackson et al., 2020). With respect to STEM identities, the *personal layer* includes the individual attributes, qualities, or beliefs that are most salient to an individual's self-concept as a 'STEM person.' The *enacted layer* comprises the ways that individuals perform or communicate their STEM identities, by engaging in STEM activities or communicating as STEM people (Linvill et al., 2019). The *relational layer* involves the co-construction of STEM identities through relationships and the identities that are ascribed within relationships, such as tutor/tutee (Agne & Muller, 2019). Finally, the *communal layer* refers to how individuals see themselves as part of a STEM group or social identity, such as a STEM professional identity, as well as how they integrate STEM identities with other social identities (Jones, 2020; Morton & Parsons, 2018).

Traditional definitions of STEM identity presume that students with stronger STEM identities experience alignment between these layers of identity; specifically, individuals who perceive themselves to be competent in STEM (personal layer), can perform that competence (enactment layer), and are recognized by others for their competence and performance (relational layer), have a strong STEM identity (Carlone & Johnson, 2007). CTI recognizes that people often experience gaps between or within identity layers (Jung & Hecht, 2004), and these identity gaps are often, but not always, experienced negatively (Brooks & Pitts, 2016; Daniels & Rittenour, 2018). With respect to STEM identities, students may experience personal-communal gaps between their personal identities and their stereotypes of STEM people as a group (Brooks, 2017); personal-enacted gaps between their perceived competence and ability to perform in STEM; and personal-relational gaps between their perceptions of themselves as STEM people and the identities they are ascribed by others (Stewart, 2022).

Underlying the CTI framework is the idea that identities are symbols and codes that guide how individuals and groups understand and interpret selves, behaviors, relationships, and group memberships (Jackson et al., 2020). Because CTI is focused on identity as a subjective process of meaning making, rather than a measurable psychological construct, we use Interpretive Phenomenological Analysis (IPA), a qualitative methodological approach that sees people as 'sense-making creatures, and therefore the accounts which participants provide will reflect their attempts to make sense of their experience' (Smith et al., 2009, p. 3). IPA has been applied to the study of a variety of identities, including donor-conceived offspring (Harrigan et al., 2015), gay men in Singapore (Bin Ibrahim & Barlas, 2021), and breast cancer survivors (Matthews & Semper, 2017). IPA has also been applied to the study of STEM identities (Kirn et al., 2019). For example, Huff et al. (2019) examined how engineering graduates transitioning from college to career negotiated tensions between their engineering professional identities, their identities outside of their work/profession, and their family role identities. Ross et al. (2021) focused on the experiences of Black women engineers and the role of nurturing and supportive structures and role models in developing their engineering identities. We extend these IPA studies of engineering identities by focusing on how current undergraduates who are 'at risk' for leaving STEM understand and experience their emerging STEM identities.

Research context

The context for this study is the Urban STEM Collaboratory, an NSF-funded program at three U.S. public urban research universities, University of Memphis (UofM), University of Colorado Denver (CU-Denver), and Indiana University Purdue University Indianapolis (IUPUI). These institutions serve a higher proportion of underrepresented minority, first generation, and post-traditional students than elite 'flagship' public institutions, and each campus attempted to recruit applicants from diverse backgrounds (e.g. through high schools and organizations that serve underrepresented groups). The study was conducted during the second year of the Collaboratory (Fall 2020–Spring 2021), with two cohorts (the first cohort began in Fall 2019, the second in Fall 2020). Across six cohorts (13–25 students) recruited over two years at the three campuses, women comprised 20%–61% and non-White students comprised 30%–70% of each cohort.

The Collaboratory provides scholarships to engineering, computer science, and/or mathematics majors who are academically well-qualified but have unmet financial need based on their Application for Federal Student Aid (FAFSA). Due to this unmet financial need, these students may be 'at risk' for leaving STEM, either dropping out of university or changing to a less demanding major because of a greater need to work outside of school. In addition to scholarships to help close their financial aid gap, the program offers participants ('Urban STEM Scholars') a variety of academic, social, and career programming to help participants build and maintain strong STEM identities across all four layers of identity as described in CTI. These programs include summer bridge programs and an academic social networking site that connects students across all three campuses, as well as mentoring, peer-led team learning, community outreach, and other activities that vary across campuses and by individual student interest. Urban STEM Scholars earn 'badges,' or micro-credentials, for their participation in Collaboratory and other STEM-related activities, are encouraged to earn a minimum number of badges (two each semester), and must maintain a minimum grade point average (2.5/4.0) to retain their scholarship. The first two years of the Collaboratory are described in more detail in Ivey et al. (2021). The current study was conducted while courses and other activities were virtual due to the COVID-19 pandemic.

Method

Participants and procedure

A total of 20 (of 68) Urban STEM Scholars from two of the three campuses[1] volunteered and completed semi-structured interviews in exchange for credit toward a badge and a gift card. All Urban STEM Scholars at these two campuses were invited to participate, and all who volunteered were included (see Table 1 for participant demographics). Study procedures were approved as 'exempt' by the two campuses' Institutional Review Boards, and participants gave verbal consent before commencing with the interviews. Each participant was assigned a random ID number (P01–P20).

The semi-structured interviews were conducted one-on-one via Zoom. The protocol for the interviews is shown in Table 2. Some participants from the first cohorts had been interviewed in the first year of the project, and these participants were asked questions about how/whether their identities had changed or shifted over time. Finally, all participants were asked questions

Table 1. Participant demographics.

Demographic category		Frequency (n)
Gender	Women	7
	Men	13
Race/Ethnicity	Asian	3
	Black/African American	5
	Hispanic/Latinx	2
	White	11
Year in college	First year	6
	Second year	5
	Third year	8
	Fourth year	1
Major	Bio/biomedical engineering	5
	Civil engineering	1
	Computer science/engineering	5
	Mechanical engineering	9

Note: 3 participants also had a second major in mathematical sciences.

about how the COVID-19 pandemic and remote learning had influenced their interactions and learning experiences. Each interview lasted 30–60 min ($M_{\text{words}} = 4735.50$; $SD = 1324.24$).

Analysis

The transcripts were analyzed following the analytic procedures for IPA as described by Smith et al. (2009). To begin the process, we (the co-authors) independently (1) read through the same randomly selected transcript and (2) made initial notes on the participants' conversational turns in that transcript within three categories: *descriptive comments*, paraphrasing the content of the

Table 2. Semi-structured interview protocol.

Questions	Relevant identity layer(s)
How would you describe your identity? What makes you who you are?	Personal and communal (how do participants describe themselves in terms of individual traits and/or social/group memberships?)
How would other people describe your identity? How do other people see you? Who sees you most similarly to how you see yourself? Why? Who sees you least similarly to how you see yourself? Why?	Relational (what identities are participants ascribed by others? what relationships are most significant in how participants co-construct their identities?)
Who do you know (other than yourself) that identifies as an engineer? Why did they become interested in engineering? Why do you think they embraced being an engineer?	Relational (what relationships inform how participants see STEM identity?)
Among your friends or classmates, how do they convey that they are engineering majors? In other words, in what ways are you reminded that they are an engineering major?	Relational and enacted (how do STEM friends and peers communicate or perform STEM identities?)
For yourself, how do you convey that you are an engineering major? In other words, in what ways do you remind others that you are an engineering major? Do you feel like others see you as an engineer major? Why or why not?	Personal, enacted, and relational (how do participants perform or communicate their own personal STEM identity? Do others ascribe to them a STEM identity?)
When you are speaking or writing as an engineer/ing major (e.g. on the CN, STEM ambassador, etc.), do you feel like you are conveying the 'real you'? Do you feel like this is consistent with who you 'really are'? Why or why not?	Personal and enacted (to what extent are participants' enacted STEM identities consistent with their personal identities?)
When you are communicating or interacting with your peers in the Urban STEM Collaboratory, do you feel like you can truly be yourself? Are there aspects of yourself that you don't express or reveal to these peers?	Personal, enacted, and relational (to what extent do participants enact their personal identities when interacting with STEM peers?)
What are some barriers or disadvantages for you that might make it more difficult to embrace a STEM major or identity? What are some opportunities or advantages for you that might make it easier to embrace a STEM major or identity?	Personal, enacted, relational, and communal (how do participants conceptualize advantages and disadvantages to developing a STEM identity? How do these advantages or disadvantages relate to identity layers or identity gaps?)

participant's statements to capture 'the participants' thoughts and experiences' (p. 84); *linguistic comments*, focusing on the participant's use of language (e.g. hedges, figurative language) to capture *how* the participants' thoughts and experiences were expressed; and *conceptual comments*, interpreting the participant's experience and understanding of their identities drawing both on ideas introduced by the participant and our 'own experiential and/or professional knowledge' (p. 89). In Step 3 we collectively discussed our notes and developed emergent themes from the transcript. As Smith et al. state, 'The main task in turning notes into themes involves an attempt to produce a concise and pithy statement of what was important in the various comments attached to a piece of transcript' (p. 92). Finally, in Step 4 we discussed the emergent themes and refined them into those that comprised 'the most interesting and important aspects of [the] participant's account' (p. 96).

After completing these steps on one transcript, the remaining 19 transcripts were randomly assigned to a team of 2 or 3 co-authors (each team included 1 social scientist with graduate-level training in qualitative methods and 1 engineer or mathematician and analyzed 4–5 transcripts). Members of each team independently completed Steps 1–3 and then discussed their notes and emergent themes collectively to complete Step 4 on each of their assigned transcripts. This process resulted in consensually agreed upon draft themes for each of the 20 transcripts. The final analytic step, 'looking for patterns across cases,' was completed by the first author, who developed a set of superordinate themes for the entire dataset based on the themes that were developed from each of the 20 transcripts. All the co-authors read and offered feedback on a draft of this analysis for completeness and accuracy with revisions made based on this feedback. We ultimately identified four broad organizing questions: What does it mean to be an engineer? How does one become an engineer? How does engineering identity intersect with other identities? How has the COVID-19 pandemic affected identity development? The findings are summarized in Table 3.

Table 3. Summary of findings.

IPA theme	IPA sub-themes	CTI implications
What does it mean to be an engineer?	Engineering Attributes	Positive self- (personal identity) and group attributions (communal identity) about STEM
	Engineering Motivations	Desire to do well financially or push oneself intellectually in STEM (personal identity) Using STEM to 'give back' or 'do good' for others (personal identity)
	Negative Attributes and Barriers	Negative group attributions (communal identity) Potential gaps between personal and ascribed (relational) STEM identities (based on negative communal/group stereotypes)
How does one become an engineer?	Early Educational and Family Influence	Opportunities to 'do' STEM early (enacted identity) Encouragement from teachers, parents, and others (relational identity)
	Peer Mentoring Relationships	Performing STEM identities within formal mentoring programs (enacted and relational identity)
	Informal Peer Relationships	Identifying with STEM peers (relational identity) and creating STEM communities (communal identity)
	College Classroom Experiences	Increasing sense of competence in STEM (personal identity) Doing and communicating STEM (enacted identity)
How does engineering intersect with other identities?	Contextual Salience	Performing and/or being ascribed different identities depending on context (enacted and relational identities)
	Identity Gaps	Gaps between self-concept (personal identity) and ascribed identities (relational identity)
	Engineering and Minoritized Identities	Potential gaps between STEM and other social identities and importance of seeing others who share social identities in STEM (communal identities)
How has the COVID-19 Pandemic Affected Identity Development?	COVID-19 and Social Interaction	Feeling disconnected from peers and using technology to maintain friendships (relational identity)
	COVID-19 and Learning	Challenges to performing academically, constraints on opportunities to do STEM (enacted identity)

Findings

What does it mean to be an engineer?

> I want to create things. I want to make things. I want to solve problems that people have, and in a different way than anyone else has before. (P18)

In this section, we discuss how participants described what it means to be an engineer. Here, we use the term engineer to refer collectively to both engineers and engineering majors (including computer scientists and computer science majors), as these descriptions often overlapped. However, we also noted in the interviews that participants made distinctions between themselves as engineering students and other majors and/or their current selves as students and their projected future selves as professional engineers. Participants expressed differing degrees of uncertainty about the extent to which their present identities overlapped with that of a professional engineer, and this uncertainty was sometimes gendered, with men tending to express more confidence than women. Below, we describe how participants described the attributes and motivations of engineers, as well as some negative aspects of being an engineer and potential barriers to becoming an engineer.

Engineering attributes. By and large, participants attributed positive qualities to engineers, such as creativity, curiosity, and problem-solving abilities (personal and communal identities). As one participant put it:

> Engineers are very creative people. When you think of the word 'engineer,' I don't think there is really anything negative with it. There are people who are innovative and creative, and I think that really aligns with what I want people to think of me, and what I certainly think of myself as. (P02)

Some saw engineers as having a particular, perhaps innate, mindset that focuses on hands-on, practical approaches to real-world problems. Passion was also key to what it means to be an engineer, and that passion would be apparent to others: 'Oh, no surprise there that you're [in] engineering. You're obsessed with this and that' (P20). Importantly, 'being good at math' was a common theme in how participants' described what it means to be an engineer. Some participants made explicit demarcations between how engineers think and how people in other disciplines (e.g. computer science) think. In addition to these cognitive attributes, being hardworking was another recurring theme. For some participants, the attribute of being hardworking contrasted with the idea of having innate or natural talent: 'you don't have to be naturally gifted at those things [math and physics] to still succeed, in my opinion' (P16). Overall, these assessments were a source of positive in-group identity for these students based on their chosen major/future career. But for some, these assessments were also associated with a sense of being a 'cut above' others: 'If everyone could do it, everyone would' (P15). However, this impression was not always perceived as positive, as will be discussed below.

Engineering motivations. Participants also described the motivations, their own and others,' for being engineers (personal identity). These motivations fell into two broad categories – doing good in the world and doing well financially. Motivations to do good in the world, or 'yearning to give back' and 'leaving the world a better place' (Carrigan, 2017, p. 1178), dovetailed with their descriptions of engineers as being practical and hands-on. Even more salient in these interviews were career and financial motivations. Perhaps unsurprisingly, given the economic uncertainty during the time these interviews were conducted, the economic stability that is expected to come with an engineering career was mentioned by several participants. At least one participant suggested that economic/financial motivations are 'impure' in comparison to other 'pure' motivations, such as intellectual interests (P20). However, for other participants, career and intellectual ambitions were seen as more aligned:

> I always get questions, like, 'why would you choose that [engineering]?' I just want to push myself. That's what I'm always trying to do. [...] I just didn't want to fall into some boring job. I wanted to do something that really challenged me. (P03)

Negative attributes and barriers. Although these participants' attributions about engineers are largely positive, some participants noted some negative attributes (communal identity). Specifically, because they perceive engineering to be an 'elite' major, some participants reported that engineering students may be overly cocky, self-confident, or braggadocious. Even if engineers do not exhibit these negative characteristics, exhibiting other characteristics of engineers may be perceived by their peers as 'alienating' or 'weird': 'And if they actually knew how I thought of things [robotics], they would probably think that I was just weird' (P12), which may make some engineers less willing to disclose their major. These possible 'gaps' between engineers' personal identities and negative identities they and/or others may ascribe to engineers represent potential barriers to their engineering identities (personal-relational identity gap). Other barriers to engineering identity described by participants included not embodying the attributes of engineers (e.g. not working hard, not being disciplined), experiencing learning differences, and encountering financial obstacles. Finally, being a woman and/or a member of an historically excluded group was also noted by some participants as a potential barrier to embracing an engineering identity, which will be discussed in more detail below.

Theoretical implications. The theme *what it means to be an engineer* implicated both personal and communal identities – how they conceptualize themselves and others as engineers both individually and collectively. While these personal and communal STEM identities are largely positive, they also acknowledged some negative attributes, which might become more salient when ascribed to them by others relationally. These negative attributions may contribute to personal-relational identity gaps. Other potential identity gaps pointed to by our participants included personal-enacted (challenges to performing a desired STEM identity) and personal-communal (perceived gaps between STEM and other social identities).

How does one become an engineer?

> I'm really getting started, and kind of going into everything. I didn't even know exactly what civil engineering really meant. And then my Intro to Civil class, that helped a lot. So, I think as I keep learning the material and everything, then I'll kind of start progressing in these circles. But yeah, just right now, [I'm] just getting started. (P03)

In this section, we discuss the different ways our participants described their journeys into becoming engineers. As undergraduates, they are, of course, still early in their journeys. They pointed to the formative experiences and important others that have helped them get to their current point, even as they acknowledged they are not yet fully engineers. Below, we describe how participants viewed the role of early exposure and educational experiences in STEM, influence of their families, recognition from others (especially in mentoring and peer relationships), and hands-on learning experiences in college in shaping their engineering identities.

Early educational and family influence. Several participants mentioned the importance of STEM educational experiences prior to college in becoming engineers (enacted identity). For example, one participant credited their ability to succeed in STEM to having taken calculus in high school, whereas classmates who only had high school algebra struggled (P06). Similarly, another participant who had not taken calculus in high school expressed that this was a source of anxiety: 'I didn't take calculus in high school. That made me feel a little bit insecure compared to my peers who had taken calculus in high school' (P01). In addition to having taken (and having had access to) advanced STEM courses in high school, the role of specific teachers (relational identity) in modeling passion for STEM was also noted:

> A big proponent for me personally was my chemistry teacher, actually. Well, he was actually my anatomy, biology, and chemistry [teacher]. He's a big big – he might be the reason I switch my major to chemical [engineering], actually. He made me so passionate about that subject, 'cause I saw, like, the passion he had for it, and how much he was just excited to teach it. And it really showed in my ACT scores that I really loved that subject specifically. (P19)

In addition to high school courses and teachers, participants credited parents with exposing them to STEM via encouraging them to participate in STEM extracurricular activities (e.g. STEM camps) or because their parents are themselves engineers. Participants described having parents and/or other family members who set them on a clear path (or, perhaps 'pressured' them [P09]) into higher education, whether in general or to study a STEM field specifically. As one participant put it, they did not know growing up that college was 'optional' (P01). Such family influence was cited by one participant (P03) as perhaps especially important for members of minoritized groups in STEM, and across the board, family members were cited as those individuals who knew the participants best and saw them most closely to the way they see themselves.

Peer mentoring relationships. In addition to family, being recognized by others as a 'STEM person' was noted by several participants as being key to their developing a STEM identity. Among those whose recognition was noted as important were faculty, co-workers, and, especially, peers. Of particular importance to these participants was how their STEM identities were recognized and enacted within peer mentoring relationships in the Urban STEM program. Participants described how being mentored led them to feel connected to and recognized by older (junior and senior) STEM students and motivated them to participate in STEM activities and achieve academically. For example:

> I think it [peer mentoring] did help a lot with how I view myself, because it gave me a motivation on, like, in my classes like when I had a mentor who was, you know, like checking up on my grades and stuff. […] And also, like, hearing advice from upperclassmen about what classes are and how they should feel and whatnot made me feel closer to, like, someone who's in, you know, the last year of mechanical engineering or second-to-last year. I felt, like, closer to those people. It wasn't like such a large gap between someone who's a freshman and then someone who's a junior or senior. (P06)

And, as students became peer mentors themselves, they found themselves embodying and enacting STEM identities as they were looked to by mentees as knowledgeable, responsible, and trustworthy representatives of a STEM community:

> A lot of what I've been trying to do as a mentor is kind of the things that really helped me as a mentee. I've preached [about] summer classes. I've tried to, like, put in those little reminders of things to keep – about, not education – in, like, the back of your head […] So, I've – it's not so much that it, like, changed myself, but it's more like I took in this helpful information when I was a mentee, and so now I'm going to try to give it back, like, as a mentor. (P17)

Informal peer relationships. Although students may stereotype STEM as being unsocial (Brooks, 2017), peer relationships, and the communities that emerge from those relationships, were particularly salient themes across interviews. Interacting within friendships with other STEM students was an important aspect to how participants described their developing engineering identities. Through these relationships, participants could see how others share their same interests in STEM fields and the same issues or struggles with STEM coursework. Peer relationships were seen as primary means for getting help with courses (i.e. becoming more competent) and for building community (i.e. creating a communal STEM identity):

> Engineering is very difficult and a lot of the ways you get through it is with help, like building up your friend group and say, 'Guys, I'm stuck on this. Do you know anything to do?' 'No, man, maybe you should do this.' And then you'll do it and everyone's like, 'Ah, of course.' (P18)

These communities, both informal and through the Urban STEM Collaboratory, also helped students to feel more connected, especially as they were physically remote from one another due to COVID-19.

> There are many group chats for different classes. The classmates will get in one big group chat. We'll ask questions about homework, help each other out on anything. And then also just closer classmates, we just maintain that friendship every now and then. If I haven't heard from them, I'll shoot them a text message, ask how it's going. Sometimes they'll do the same for me. We just set up times when we're both available to get on Zoom, work on some homework. (P13)

College classroom experiences. Finally, formal classroom experiences were an important part of how students described developing their (enacted) engineering identities. The experiences that were most salient for students went beyond developing competency, although that was noted as important, but tied together other threads in their interviews. They emphasized the practical, hands-on nature of their coursework, for example, using coding to analyze data or building prototypes. Projects require teamwork and interaction with their peers and immersion into real-world scenarios. As one participant stated, engineering requires communication and interaction, because '[t]here's no real reason to create something if you can't really explain what it does or show people the reason why you created it in the first place' (P04). All these descriptions highlight that engineering must be enacted, that one becomes an engineer by doing engineering. As one participant put it, 'So I'm starting to have more and more things like to say that I've done or that I'm doing that are … kind of coincide with my STEM identity' (P17).

Theoretical implications. How one becomes an engineer implicated both enacted and relational identities. Enacting STEM identities – 'doing STEM' – not only in college but during K-12 were, of course, important, and lack of opportunity to do so represented a potential personal-enacted STEM identity gap. Enacting STEM identities was embedded within relational identities, primarily with parents and teachers in K-12 and with peers, both formally and informally, in college. Relational STEM identities in the form of peer relationships contributed to communal STEM identities in the form of STEM community.

How does engineering identity intersect with other identities?

> A lot of people at my high school, they didn't see themselves as going into STEM because they thought, well, they just weren't represented enough. So yeah. Well, they didn't go to, a lot of them decided not even to go to college because they didn't think it was for them. (P07)

Engineering identity is, of course, only one aspect of these participants' identities. Participants pointed to a variety of identities based on their personal characteristics, relationships, and social identities. In this section, we describe how participants' engineering identities were more or less salient in different social contexts, gaps between different aspects of their identities, and how engineering identity intersects with minoritized social identities.

Contextual salience. Several participants discussed how their engineering identity could be 'compartmentalized' from other identities depending on context: 'But if a normal everyday person saw me, they're like, 'Oh, I didn't know he would be an engineering student.' 'Cause I like other things as well, like basketball and video gaming' (P12). Among friends or family, they may enact, or be ascribed, a more general 'student' identity as opposed to a more specific engineering identity. For example, in the following excerpt a participant describes how, even as they are developing a more specific STEM identity as they move closer to graduation, their family perceives them (ascribed relational identity) more broadly as a student (as opposed to a mechanical engineer):

> I'm not gonna, like, precisely be talking about STEM all the time when I'm with my family, 'cause I talked about it all day at school. […] Not that I haven't changed at all since like junior year of high school, but it's … it's still like they're seeing me still as a student. Like I'm on my journey in, like, education and becoming like the person with the STEM identity who's going to go into a career. And that, like, hasn't changed from like early education into now my undergrad. It's like I'm still … throughout that whole thing, I've been on like my education journey. And that's how, like, people like that, especially my parents, I think that's how they, like, mostly perceive me in relation to that STEM identity. (P17)

Markers of an enacted student identity (e.g. studying, wearing a backpack, etc.) are the most broadly legible to others, whereas markers of STEM identity are most relevant in contexts with other engineers. Other, significant communal identities, such as Reserve Officers' Training Corps (ROTC), would also be more salient than engineering identity when participating in those groups:

> I guess there's those at my ROTC. Basically, we all see each other as cadets or future military leaders. Our priority there isn't basically engineering. It's more-so leading future soldiers into battle or just trying to protect the country. (P04)

Identity gaps. Some participants also indicated gaps between their personal or relational ascribed identities and communal STEM identity. For some, this was expressed as uncertainty about the extent to which their current engineering identity is consistent with their idea of a professional engineer. For example, one participant framed their idea of a professional engineer as a 'stereotype' that they were uncertain they fit, but at the same time, they did not see themselves pursuing a different field of study:

> I guess it's asking kind of about, like, the stereotype. How well you fit the stereotype. And it's like I'm not too sure about it. But it's like I can't really see myself as being a different major at this point in time. (P17)

Other participants described gaps between how they are perceived and how others perceive engineers. For example, 'My image physically, I wouldn't look like a – I would say STEM majors are nerdy. And I like being a nerd, but I wouldn't look like the smart type' (P19). Another participant (P16) described gaps between her enacted identity ('bubbly'), the identity that is often ascribed to her ('ditzy'), and her personal identity ('smart'), attributing the gap between the ascribed and personal identity to her gender identity ('bubbly' women are not perceived as 'smart').

Engineering and minoritized identities. Finally, women and members of other historically excluded groups in STEM noted potential gaps between engineering identity and their other social (communal) identities, as well as the importance of having peers and mentors in STEM who share these identities. One participant (P01) identified that being a woman and/or minority is a specific disadvantage in STEM, noting that there are few women in her major department, which makes it difficult for her to make friends with others in her major. She also noted that some STEM fields, like biomedical engineering, biology, or chemistry, have more women. Another participant (P03) described being in a STEM field with few women as an important challenge to take on, describing herself as a 'vanguard' in her field. Other participants described how important it is to see people who share their social identities in STEM fields – both peers and teachers/mentors – to encourage them to pursue STEM studies:

> He's just like me. He's an immigrant, and then he's teaching math at the University of Memphis, so I say [to] myself, 'He made it, so I can make it too.' (P11)

> Yes, representation matters. And just a lot of people, especially in underrepresented communities, they don't have people to look up to. And she was my person because she was [like me]. She was like a friend, but also a mentor. She just took me under her wing and taught me about what she does. (P07)

We also noted that participants whose social identities are not minoritized in engineering (white, male) tended not to mention their social identities as a potential advantage nor did they mention not sharing these identities as potential disadvantages.

Theoretical implications. How STEM identity intersects with other identities implicated enacted, relational, and communal identities. Depending on context, participants may enact or be ascribed identities other than their STEM identities; sometimes, there may be gaps between these ascribed relational identities students' personal STEM identities, if friends or family, for instance, do not relate to them as a STEM person. Participants whose social identities are minoritized in STEM pointed to the importance of having shared social (communal) identity with other STEM people and, therefore, a potential communal-communal gap between minoritized and STEM social identities.

How has the COVID-19 pandemic affected identity development?

> I'm sitting in my room right now, and this is where everything happens. Every single thing in my life happens in this room, and sometimes it drives me crazy, because I don't know how to separate my work life, my school

> life, my personal life, my everything, my commitments. I'm sitting in my bed and I'm trying to relax, and I'm thinking about my laptop which is probably like 10 feet away from me. (P01)

These interviews were conducted during the COVID-19 pandemic, when both campuses were shut down and almost all instructional and other activities were held remotely. The campus shutdowns therefore affected students' opportunities for both formal learning and socializing in person. Because both increasing competence through hands-on learning (enacted identity) and informal and formal peer relationships (relational identity) were identified as key aspects of engineering identity, in this section, we consider how our participants experienced the impacts of the pandemic on their social interactions and learning.

COVID-19 and social interaction. Not surprisingly, most participants noted that their social interactions had been substantially constrained due to remote learning. They noted that it was harder to get to know classmates whom they only interact with via Zoom and often, their closest friendships were those they had made before the pandemic. Incidental interactions before or after class or in other spaces on campus were non-existent, and making new friends required much more planning and intentionality. These are the kinds of interactions, with other engineers, that were perceived as particularly important to engineering identity. However, many participants indicated that they still maintained meaningful friendships with their peers, and, in some cases, their friendships were closer, but with fewer people. In addition to feeling disconnected from peers, they also felt disconnected from place, lacking connection to their campus, and feeling stress from spending so much of their time in one room, often in their parents' home. First-year students, who had no pre-COVID experience as college students, were especially affected by being remote. No participant expressed a desire to remain remote the next academic year. Although most participants experienced being remote from one another negatively, some also positively noted their use of text messaging and Discord to maintain their relationships: 'We've been able to go around COVID and get together virtually, which is very nice. And it helps mentally, 100%' (P19).

COVID-19 and learning. Participants also discussed how remote education constrained their learning, which hindered their opportunities to develop and perform STEM competence (enacted identity). They noted that they were getting much less of the kinds of hands-on experiences they would get in the classroom, and other technical difficulties associated with Zoom. Because they were taking classes at home, they noted that they were easily distracted and otherwise had difficulty concentrating on their studies: 'I'd like to think I would be performing better if it was in person. I'm still trying my hardest but sitting in this chair every day in front of these monitors … ' (P02). Another participant expressed that it was more difficult to understand and manage assignments when they are only posted on the learning management system rather than discussed face-to-face in the classroom (P10). Some students expressed that they were concerned that they were not learning what they would need to know to succeed in future courses or in internships; similarly, they worried that the pandemic would mean fewer internship opportunities and perhaps reduced job prospects in the future. One participant (P01) acknowledged that remote learning facilitated cheating in courses. Of course, not all experiences with online learning were negative, and some students took advantage of the affordances of Zoom to enhance their learning: 'We kind of just meet up on Zoom, and one of us will share our screens [to play back the lecture], and we'll go through and if we don't understand something, we'll ask. Typically, there's someone who understands' (P05).

Theoretical implications. The COVID-19 pandemic posed challenges to both relational and enacted STEM identities. Being remote meant fewer opportunities to interact with peers but also required more intentionality in maintaining existing peer relationships. Remote learning also limited participants' opportunities to enact their STEM identities in the classroom and to 'do STEM' in other settings.

Discussion

In the above analysis, we sought to learn how our participants – 'at risk' STEM undergraduates – subjectively understood and experienced their STEM identities. We approached STEM identity from a CTI perspective, as a communication process built by and within interactions and relationships and located not only within individuals but also within groups and communities. Using IPA as a method, we attended to participants' own accounts and the feelings and emotions that attached to those accounts before moving to broader interpretive categories. Integrating communicative and phenomenological approaches thus offers a more comprehensive understanding of these students' STEM identities than approaches that focus on identities as personal attributes or representational categories, which are most common in the literature (Simpson & Bouhafa, 2020), and especially foreground enacted and relational identities which are less well represented (Kim & Sinatra, 2018).

The analysis revealed some of the key features, as well as some potential tensions, in how these 'at risk' STEM majors understand and experience their STEM identities. By and large, they understood being an engineer as a positive thing, but they also expressed varying degrees of certainty in their own STEM identity. Some uncertainty was rooted in the extent to which they perceived a 'gap' between their current student and potential professional identities, or the extent with which they perceive themselves, or are perceived by others, as fulfilling the 'stereotype' of an engineer (Nadelson et al., 2015). Although they noted the importance of formal educational experiences and mentoring from faculty and others (Stitt Richardson et al., 2020), they especially credited peer relationships and interactions – both through peer mentoring and informal relationships within the Urban STEM Collaboratory – as being central to their developing STEM identities (Espinosa, 2011; Huvard et al., 2020). Through these interactions and relationships, they helped each other build STEM competence and share similar experiences and challenges. Those whose social identities are marginalized and minoritized in STEM spoke of the importance of seeing and interacting with STEM people who share their social identities in developing their own STEM identities (Jones, 2020).

These findings also add nuance to analyses of STEM identities as personal attributes. Survey data of Urban STEM Scholars portray a relatively uncomplicated portrait of students with strong STEM identities, obscuring some of the uncertainties described by our participants and the processes by which these students come to develop their STEM identities (Ivey et al., 2021). Similarly, although understanding how 'representational' identities based on gender, race/ethnicity, social class, etc., intersect with STEM identities is an important impetus for research in this field, it is also important to understand how all different layers of identity fit together, or not, in how students' experience their STEM identities. Among our participants, being a woman and/or a member of other minoritized groups was part of how they understood and described their STEM identities, but not exclusively or overwhelmingly so.

The results of this and other studies of STEM identities using a CTI framework (Brooks, 2017; Stewart, 2022; Washington, 2022) are consistent with what might be called a Communication Theory of STEM Identities, comprising four layers, and pointing to potential gaps between these layers (see Figure 1). Personal STEM identities comprise an individual's self-cognitions relevant to their STEM identity, including ones that are specific to STEM (e.g. competence and self-efficacy in STEM) and others that are more general but relevant to how they define themselves as STEM people (e.g. hardworking, intelligent). Enacted STEM identities comprise one's performance of STEM competence (e.g. doing well in STEM coursework) and communicating STEM identity more broadly (e.g. speaking and writing as a 'STEM person'). Relational STEM identities comprise how individuals co-construct their STEM identities within relationships with family members, teachers, and peers, and how or whether STEM identities are ascribed to them by others. Finally, communal STEM identities comprise formal and informal STEM communities, as well as group stereotypes, both positive and negative, about STEM people.

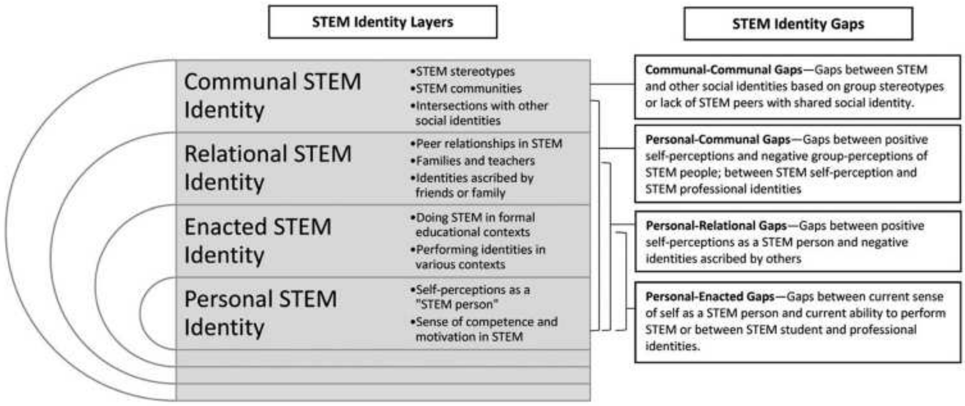

Figure 1. A communication theory of STEM identities.

These identity layers are not, it is important to reiterate, separate from one another, but are interpenetrating. For instance, being a STEM person is, as Carlone and Johnson's (2007) framework highlights, about enacting or performing STEM competence and having those performances recognized by others. But beyond being recognized, being a STEM person also relies on relationships with peers in STEM and being ascribed a STEM identity by friends, family, and others both in and outside of STEM. There are also important potential gaps between identity layers that may serve as barriers to STEM identity development. STEM identities may not be ascribed by others when social identities (based on gender or race, for example) do not align with STEM group stereotypes, or one may not see their own individual personality aligning with their STEM group stereotypes (they may see being a STEM person as a negative social identity; Starr, 2018). Similarly, they may see themselves differently from how they see other STEM peers or see a gap between how they perceive their STEM competence and what they need to be able to perform to match that of STEM peers or professionals. These and other potential STEM identity gaps are ripe for future research to identify and refine.

There are, of course, limitations to this study. All our participants are engineering majors, so these findings may not apply to other STEM disciplines. However, they do represent an array of engineering/STEM disciplines, including computer science (which is not always included under engineering), bio/biomedical (overlapping with biology), mechanical (overlapping with physics), and mathematics double-majors, highlighting the fuzzy boundaries between STEM disciplines (Simpson & Bouhafa, 2020). Likewise, our participants are part of a program designed to help build and strengthen their STEM identities and are not representative of all 'at risk' STEM majors on their campuses or in general. As a volunteer sample, they may not be representative of the broader group of Urban STEM scholars.

This study shows how a CTI framework can elucidate students' STEM identity journeys within and across layers and theorize barriers to STEM identities in terms of 'identity gaps' between layers. From a practical/applied perspective, it helps to build interventions, such as the Urban STEM Collaboratory, that are attentive to different aspects of students' STEM identities (Washington, 2022). From a theoretical perspective it extends and integrates approaches focusing on STEM identities as personal attributes, STEM performance and recognition (Carlone & Johnson, 2007), contextually enacted and relational (Kim & Sinatra, 2018), and/or as social or group identities.

Note

1. One campus was excluded to accommodate separate focus groups which were being conducted for evaluation purposes.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: National Science Foundation S-STEM Grants #1833987 (UofM), #1833983 (CU-Denver), #1833817 (IUPUI).

Ethical statement

This research was reviewed and approved by the Institutional Review Boards at the University of Memphis (PRO-FY2019-20) and University of Colorado Denver (18-1408).

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