Fan *et al.*
International Journal of STEM Education (2023) 10:22
https://doi.org/10.1186/s40594-023-00412-z

International Journal of STEM Education

RESEARCH

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Possible future selves in STEM: an epistemic network analysis of identity exploration in minoritized students and alumni

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Abstract

Background STEM minority participation programs have been widely implemented in higher education with the goal of diversifying the global STEM workforce. Informed by research highlighting the potential of targeted exploration of STEM roles and reflection on the *self* in relation to STEM (identity exploration), this work examines how engagement in a government funded STEM minority participation program shaped these processes in current students and program alumni.

Results Epistemic network analysis (ENA) was used to visualize conceptual connections between identity themes that emerged from interviews with present and past program participants. Network models were developed for current students and alumni for cross-group comparisons. Differences were found in how participants at different stages of their careers enact and describe their identity exploration processes. Summative network models highlighted how students discussed action-taking (sometimes through participation in STEM minority program initiatives) as they explored less-certain possible future STEM roles, while alumni integrated more diverse and holistic facets of their identities when conceptualizing their futures. To close the interpretive loop, a qualitative interpretation of interview discourse was used to give context to network patterns.

Conclusions Results highlight the differences between novices' and professionals' conceptualizations of their future selves and illustrate how minoritized individuals describe their long-term patterns of identity exploration related to STEM majors and careers. Implications for future STEM identity research and practice, including higher education programming as a tool to support students' STEM identity exploration processes, are discussed.

Keywords STEM minority participation, STEM majors and careers, Identity exploration, Possible future selves, Epistemic network analysis

Introduction

There is a growing need for a more qualified science, technology, engineering, and mathematics (STEM) workforce, both in the United States (Fayer et al., 2017) and worldwide (Burrell, 2020). This concern is exacerbated by a representation gap in terms of STEM minority participation (Camilli & Hira, 2019), which suggests a large potential untapped resource of minoritized individuals who can and should, but currently do not successfully attain STEM majors and careers. In addition to supporting equity for all STEM learners, research also highlights the benefits of a diverse workforce on STEM outcomes: more creative solutions to problems and increased productivity due to unique perspectives from team members of heterogeneous identities (Ely & Thomas, 2020). To address this persistent, global issue of equity and to advance diversity in STEM, researchers have stressed the need for initiatives that can help

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to sustain, enlarge, and diversify participation in the STEM pipeline (e.g., Doerschuk et al., 2016; Smith & Garcia, 2018). Given that college experiences have been highlighted as an influential part of the development of underrepresented minority (URM) students' interests and choices in STEM (e.g., Gasman et al., 2017; Marco-Bujosa et al., 2020), one way to achieve this is through programming at the postsecondary level that encourages URM youth to declare STEM majors and provide institutional-level support throughout their completion of STEM degrees. A long-standing example in the United States is the Louis Stokes Alliance for Minority Participation, which funds college-level programming aimed at increasing the number of students successfully declaring and completing degree programs in STEM disciplines.

In higher education contexts, research aimed at understanding how to best support STEM minority participation often emphasizes identity exploration as a way to (a) encourage student self-efficacy in STEM (e.g., Syed et al., 2019), (b) support intentional self-awareness and self-authorship in STEM fields (e.g., Morton & Parsons, 2018), (c) sustain long-term engagement and motivation to persist in STEM (e.g., Destin & Williams, 2020; Hernandez et al., 2013), and (d) enhance skills in self-monitoring and self-regulation toward the achievement of STEM goals (e.g., Park et al., 2019). These interconnected cognitive, affective, behavioral, and self-definitional features in identity scholarship are more broadly defined as *identity exploration*, or the "deliberate internal or external action of seeking and processing information in relation to the self" over time (Flum & Kaplan, 2006, p. 100).

From this perspective, we conceptualize STEM learning as a process of identity exploration over time, or a gradual enculturation into contextually specific STEM discourse and practices (Foster, 2014; Foster & Shah, 2021). An important part of this long-term process is learner reflection on *possible future selves* in STEM, or the roles and characteristics an individual hopes or expects to 1-day embody (Markus & Nurius, 1986; Oyserman, 2015). Intentional reflection on possible future selves has been shown to play a key role in academic development, engagement, retention, and career certainty (e.g., Apple et al., 2020; Kang et al., 2019; Syed et al., 2019; Verdin et al., 2018). For example, a learner might enact identity exploration around an engineering role by repeatedly choosing to engage with authentic engineering knowledge and skills, values and interests, behaviors and choices, all with a possible future self of an "engineer" in mind.

While identity-focused research has become increasingly prevalent, more nuanced examinations of long-term STEM identity exploration, particularly as related to possible future selves, are needed (Fan et al., 2022). Existing identity-focused research tends to explore learners' *current* STEM identities (e.g., Atkins et al., 2020, Seyranian et al., 2018), and despite the known benefits of intentional reflection on possible *future* selves, there has been less consideration of the reflective meaning-making process of possible *future* identities in STEM (i.e., what a learner wants or expects to be in future; Foster, 2014). Extant research on identity exploration also trends toward samples of student cohorts at early stages of their STEM careers (i.e., K-12 and college students) (e.g., Destin & Williams, 2020; Kim et al., 2018; Martin-Hansen, 2018). While valuable, this body of research only elucidates how learners navigate one phase of STEM engagement rather than providing insight into the broader evolution of STEM identities over time. For example, research is limited that compares identity exploration processes between students and alumni from minoritized backgrounds. To compound this limitation, longitudinal studies of identity exploration in STEM that are available often draw from large-scale survey or questionnaire data (e.g., Estrada et al., 2018; Hernandez et al., 2013; Park et al., 2018), which are less likely to capture nuances in how learners describe and discuss their identity exploration in their own words.

The purpose of this study is to add to scholarly knowledge on the long-term outcomes of higher education STEM minority programs in terms of identity exploration with a focus on possible future identities in STEM. We offer in-depth examinations of how minoritized individuals at different stages of their STEM professional journeys (students and alumni) engage in identity exploration around their possible future selves. The pathway was explored based on participants' own reflection on their STEM trajectory—how participants described their processes of working toward STEM degrees or career goals. To help capture reflective nuance in participants' conceptualizations of self, we leveraged quantitative ethnographic techniques (Shaffer et al., 2016) to visualize associations between inductively derived identity codes in interview discourse. The research question asks, "How do minoritized students and alumni describe their identity exploration processes when asked to reflect on their possible future selves in STEM?".

Overview of literature

STEM minority participation and programming

Women and members of historically marginalized groups remain underrepresented in STEM majors and careers (Habig et al., 2020). This speaks to the long-standing issue of equity that often manifests as systematic obstacles and challenges faced by minoritized individuals in STEM, such as structural racism (McGee, 2020), negative stereotypes (Payton & Berki, 2019), alienation, lack

of same-race support networks, and lack of pre-college STEM preparation (Rottinghaus et al., 2018). While specific contexts may differ, concerns over equity and representation in STEM have been highlighted in scholarship based on the US and many other countries (e.g., Ho et al., 2020; López-Aguirre, 2019; Ro et al., 2021; Timms et al., 2018). Diversifying and sustaining the STEM pipeline has been highlighted as a key to broadening participation in STEM (Doerschuk et al., 2016; Smith & Garcia, 2018). The concept of a STEM pipeline, while criticized over the years for implying a singular pathway into STEM (e.g., Petray et al., 2019), has utility for framing STEM participation as a long-term pathway of *identity exploration* that involves intentional and repeated process of enculturation into authentic STEM practices over time. From an equity perspective, this conceptualization has value for elucidating, understanding, normalizing and supporting the long-term lived experiences of minoritized groups as they pursue majors and careers in STEM.

There is evidence that STEM minority participation programs and initiatives, particularly those that foster facets of identity exploration, can effectively broaden participation and advance equity in STEM fields. Crawford et al. (2018) noted a reduction in the achievement gap between underrepresented/female participants and majority males in a STEM scholarship program when interventions such as early engagement in STEM research and an emphasis on STEM "self-image" were implemented. When assessing the impact of extra-curricular workshops and other interventions provided by a STEM-career-focused university program, Slovacek and colleagues (2019) found increases in student interest and confidence around STEM academics and careers, as well as an increasing sense of belonging. College programming such as career counseling also contributes to minoritized students' knowledge and retention in STEM (Belser et al., 2018). From such studies, we learn that STEM programming at an institutional level that supports students' identity exploration process, whether directly through specific initiatives or indirectly through cultivating a supportive campus environment, can facilitate URM learning and retention in STEM fields.

On the other hand, some research suggests that some existing STEM programming may not optimally support robust identity exploration processes. McGee (2020) argues that many universities design and institutionalize their diversity mentoring programs mostly to "assimilate" underrepresented students of color into STEM, despite calls for programming that celebrates URM self-authorship in STEM contexts (Morton & Parsons, 2018). Similarly, Armstrong and Jovanovic's (2017) examination of STEM programming across 18 universities reveals a lack of holistic approaches in these programs to support intersectional identity. Ultimately, these findings underscore the need for research grounded in identity theory and informed by URM participants' self-directed reflections that connect to the STEM roles, goals, and characteristics in the process of identity exploration.

Identity exploration in STEM

Identity exploration (Flum & Kaplan, 2006; Kaplan et al., 2020) is broadly conceptualized as an intentional and self-directed activity that has foundations in developmental identity literature (e.g., Erikson, 1959; Marcia, 1966), in that how a learner self-reflects in one moment is meaningfully built upon their prior experiences and prior conceptualizations of self. As defined by the Projective Reflection framework (Foster, 2014; Foster et al., 2019), identity exploration often unfolds through reflection on: (1) cognitive features of the self, or what STEM skills or knowledge the individual may possess, (2) affective features such as an individual's interest and valuing of the STEM topic or career, (3) behavioral features of the self, or processes of goal-setting, self-monitoring, and regulatory actions an individual enacts to achieve their STEM goals, and (4) self-definitions and self-perceptions, or assessments of the individual's own confidence, characteristics, and roles they embody or hope to 1-day enact (see Kaplan & Garner, 2017; Kaplan et al., 2020).

Research suggests that facets of identity exploration play a significant role in URMs' engagement with STEM in terms of future major/career aspirations and choices. These facets correspond to the identity exploration features discussed above, including (1) motivational constructs such as the interests and values one associates with STEM topics (e.g.,Gottlieb, 2018; Lv et al., 2022), (2) STEM self-efficacy (e.g., Jiang et al., 2020; Turner et al., 2022), and (3) self-perceptions, or the ways a learner sees themself in STEM (e.g., Collins, 2018; Morton & Parsons., 2018). These identity-related constructs can be fostered by external factors such as social influences from family, friends, or mentors (e.g., Atkins et al., 2020; Tey et al., 2020), pre-college experiences with STEM (Miller et al., 2017; Phelps et al., 2018), exposure to STEM career knowledge (Blotnicky et al., 2018; Murcia et al., 2020), and campus environment (Castellanos, 2018).

These examples of scholarship in identity and identity exploration in STEM tend to focus on a single phase or stage within the STEM pipeline, including K-12 (e.g., Foster et al., 2019; Steinke, 2017), higher education (e.g., Duran & Jones, 2020; Ortiz et al., 2019), or the workplace (e.g., Alfred et al., 2019; Ross et al., 2017). This contrasts with the growing body of identity literature that understands identity exploration as a long-term, developmental process. Kelly and colleagues' (2020) comparison of university students and professionals' professional

STEM identity status, for example, used Professional Identity Status Questionnaire (PISQ-5d) to understand differences across cohorts, but responses were limited to structured, pre-determined constructs rather than more open-ended reflection that demonstrated reflective nuance. Examining STEM identity at different stages within the STEM pathways, by means such as comparing novices' (students) and professionals' (alumni) conceptualization of self, may help illuminate the nuanced changes that emerge across the pathway of identity exploration exacted by minoritized individuals in STEM.

Future selves in STEM

Existing identity-focused research often connects current STEM identity (i.e., seeing the *self* as part of the STEM community) to improved outcomes in STEM learning and increased likelihood to choose a STEM career (e.g., Atkins et al., 2020; Norman et al., 2021; Seyranian et al., 2018). However, evidence suggests that having a *current* identity and values in STEM may not always be predictive of STEM career success more than 4 year post-graduation (Estrada et al., 2018). This disconnect could be representative of research that emphasizes reflection on the *current self* as a STEM community member over reflections on a *possible future self* in a STEM career. From a developmental perspective, learners craft possible future selves from an awareness of what they would like, expect, or in some cases fear becoming in the future (Markus & Nurius, 1986). As a result, robust identity exploration processes can and should include intentional reflections on future selves (Oyserman, 2015). This highlights the necessity to move beyond only discussions on current identity and to include possible future selves in STEM learning.

While examples do exist that explore the benefits of intentional reflection on possible future selves (e.g., Apple et al., 2020; Kang et al., 2019; Syed et al., 2019; Verdin et al., 2018), fewer works focus on how this reflective process manifests. An examination of nascent research on this topic also reveals an emphasis on *pre-college* students. For instance, Allen and Eisenhart (2017) found that young women of color in high school had to repeatedly fight for ideal future selves in STEM amid discursive and social relations that threatened to position them differently, usually in the negative light. Self-perception in relation to science was found to be the strongest predictor of identification with STEM-related careers among middle-school girls of color (Kang et al., 2018). These example investigations into URM students' possible future selves remain limited in both number and scope, highlighting the need for identity research at *post-secondary* and *professional* levels. A systematic review of STEM identity literature suggests adult participants were in the least investigated grade/age bands (Simpson & Bouhafa, 2020). In addition, studies that explore differences in reflections on *possible future selves* at different stages within the STEM pipeline may contribute needed nuance to theoretical understandings of identity exploration. The current work seeks to contribute to these areas by examining reflective processes on possible future selves enacted by postsecondary students and professionals from underrepresented backgrounds in STEM.

Examining identity exploration

Given the complexity of identity exploration as a long-term reflective process, research methods for investigating this process should facilitate this complexity. Existing longitudinal studies of STEM identity exploration tend to be questionnaire- or survey-based (e.g., Habig et al., 2020; Hotle & Katz., 2018; Jelk & Crain, 2020), which can support the modeling of causal or correlational relationships between identity constructs and STEM with large populations. Despite these benefits, these commonly used data collection techniques tend to limit the variability of student reflection to brief, controlled prompts. As such, they may not offer insight into the complex and unique STEM identity exploration as conceptualized by URM individuals across their lives and careers.

To address this, quantitative ethnographic approaches such as epistemic network analysis (ENA) have been highlighted as a useful tool for "identifying and quantifying connections among elements in coded data and representing them in dynamic network models" (Shaffer, et al., 2016, p. 9). Quantitative ethnography involves the systematization of complex or large-scale data (often qualitative discourse), so that underlying patterns and connection-making may be visualized and interpreted (Shaffer, 2018), while ENA serves as a mathematical technique for visually and statistically comparing patterns across groups. Compared to traditional non-network methods such as surveys, quantitative ethnographic methods such as ENA features a more grounded approach that allows meaning-making patterns to emerge from situated, conversation-based discourse (Andrist et al., 2015; Kaliisa et al., 2021). This is why ENA works particularly well with semi-structured interviews (as in this case) and collaborative learning logs. A systematic review found that a majority of empirical studies in education using ENA over the last decade utilized data from online discussions (23.7%), followed by interview transcripts (21.1%), and learners' interactions (17.1%); those based on interview transcripts typically explored epistemic networks in the communities of practice, games and assignment interviews, students' sense-making of feedback and reading strategies (Elmoazen et al., 2022).

Our prior work has leveraged quantitative ethnographic techniques to examine identity exploration trajectories among middle school science students (Foster, 2014; Foster et al., 2019) and longitudinally in online engineering gaming communities (Barany & Foster, 2021). This study extends this line of inquiry through a quantitative ethnographic examination of identity exploration using student and alumni interview reflections on their possible future selves as they engaged with Northeast AMP. ENA was used to visualize connections between identity themes at different stages of participants' lives and careers.

Methods

This work is a part of a larger NSF-sponsored project that funds programs intended to increase the number of underrepresented minority students earning baccalaureate degrees in STEM. The Northeast regional alliance of the Louis Stokes Alliance for Minority Participation (Northeast AMP, pseudonym) represents a diverse alliance of public and private, 2 and 4 years, research and non-research, Historically Black Colleges and Universities (HBCUs), community colleges, and majority institutions in the Northeast United States. Programming funded by Northeast AMP varies by institution to best meet the needs of each school population, but broadly consists of (a) counseling opportunities (e.g., career counseling), (b) academic support (e.g., tutoring), (c) mentorship opportunities (e.g., research apprenticeship), (d) financial support, (e) professional opportunities (e.g., workshops, job fairs), and (f) other support and enrichment (e.g., student organizations, volunteer opportunities). While the full research project involves the collection and analysis of multiple sources of data from participating institutions, leaders, and participants (students and alumni), this work examines individual interview data with current and former Northeast AMP participants, who were contacted via email to complete a survey and subsequently invited to participate in a follow-up interview.

Participants

Out of 129 participants who responded to an identity survey designed for Northeast AMP participants in the Academic Years 2020–2021 (see Fan et al., 2022), 25 participants agreed to participate in follow-up interviews. Twenty-one interviewees explicitly discussed facets of their identity exploration process as it related to their possible future selves, which formed the final sample representing four different Northeast AMP participating institutions. The sample consists of eleven students and ten alumni from various STEM disciplines. Sixteen participants chose science-related topics and five chose engineering-related topics. Examples of specific STEM disciplines represented include mechanical engineering, civil engineering, and biochemistry. Participants also identified themselves at different stages within the STEM pipeline, ranging from Freshmen in college to interns/associates and senior leaders in their STEM careers. Alumni in the sample represented those who graduated as early as 1995 to those who recently graduated in 2021. Excluding two participants who did not report their exact year of enrollment/years since graduation, the average years since postsecondary enrollment among all participants was approximately 13, and the median was 6. Fourteen participants identified as female, and seven as male. Fifteen participants identified as African American, three identified as Latinx, one as Asian American, one as biracial, and one chose not to report race or ethnicity.

Data collection

Interviews were conducted via zoom for approximately an hour of semi-structured discussion and reflection on their identity exploration processes as they related to participation in Northeast AMP programming. Interview processes were loosely guided by two interview protocols (one for alumni, one for students) that were developed collectively by the research team based on STEM identity theories and relevant literature, as well as specific inquiries from institutional leaders. Protocol differences consisted largely of changes in the tense or framing of some questions, but not the overall content (e.g., students were asked "where do you see yourself on your academic and career trajectory?" and alumni were asked "where do you see yourself on your career trajectory?"), while the majority of prompting reflective questions remained the same (e.g., "How do you think your participation in Northeast AMP influenced you as you worked toward your STEM major and career?"). All interviews were recorded and transcribed verbatim for analysis.

To explore participants' discussions of identity exploration-related specifically to conceptualizations of their possible future selves, a subset of each interview was then developed for the final data set, consisting of participant responses to questions pertaining to these topics. This resulted in 107 lines/sentences of interview data for analysis. For example, participant responses to interview prompts such as "what career would you like to have in the future" and "Do you feel like you are on track for success? Why or why not" were included in the final data set for analysis, while responses to prompts such as "Has there been a situation where you felt you needed help or support as you explored your STEM topic" were excluded, because the former subset tended to more directly reflect participants' conceptualizations of possible future selves.

Table 1 Codes related to northeast AMP participants' possible future selves in STEM

Code	Definition	Exemplary Quote
Current Interest	Current individual/personalized preferences (liking or enjoyment)	"I really love looking at the way plants and animals do things." (Student 9, Mechanical Engineering)
Current Valuing	How a topic, domain, behavior, task, choice, career, etc. is personally useful or valuable	"I would like to be involved with students teaching, mentoring and like spirituality or counselling, because that forms a big basis in my life." (Alumni 5, Chemistry)
Self-Efficacy	Confidence in one's own ability to achieve intended results/goals (Bandura, 1977, 1986)	"I'm a problem solver, and I'm a critical thinker, and that's what I want to do." (Alumni 3, Biomechanics)
Self-Definition	Elements of one's current identity or self-concept (Oyserman & James, 2011)	"I'm one of those weird engineers who does not mind reading regulations." (Alumni 7, Civil Engineering)
Taking Actions	Actions or steps one is currently taking or is about to take to achieve intended results/goals	"I'm pursuing a program, where you just do a 1-year research program and then you can become a physician–scientist later on." (Student 1, Molecular Biology)
Future Career Role	Roles or positions one expects or desires to take on in the future	"I'm looking at professorship." (Student 2, Biomechanics)
Future Career Field	Fields or disciplines in which one expects or desires to work in the future	"I chose to be a bio major, because I want to go into the med field, or I want to go to med school and work in the medical field." (Student 4, Biology)
Future Skills Used	Skills one expects to have and/or use in future careers	"As far as promotion…it would be an operations manager that chiefly manages the personnel and the overall big picture." (Alumni 9, Civil Engineering)
More Certain Future	Certainty and/or specificity in one's future career role, field, or skills	"I definitely want to stay in tech." (Student 11, Electrical Engineering)
Less Certain Future	A lack of certainty or specificity in one's future in STEM	"As far as what I want to do at the end of the program, honestly I'm not really sure." (Student 11, Electrical Engineering)
Career Change	Intentions or plans to change (or not to change) major or career in the future	"I honestly do not feel like doing that [position], because… it becomes more of a business administration." (Alumni 9, Civil Engineering)
Role Models	Individuals who have inspired one's future major or career choices	"I've had mentors talk to me about like the MD route and then go and do PhD or starting with PhD." (Student 1, Molecular Biology)

Data analysis

A priori themes were selected by the researchers using an inductive thematic analysis (Creswell, 2015), involving the identification and iterative development of topics that emerged based on an open-ended review of the transcripts (see Table 1). While the process of code development was inductive based on the content of interview discourse, codes were framed based on the theoretical positioning of identity exploration and possible future selves research discussed above. Some of the identity constructs, particularly self-efficacy and self-definition, were defined in alignment with past identity literature (see, for example, Foster, 2014; Bandura, 1977, 1986; Erikson, 1958; Flum & Kaplan, 2006; Oyserman & James, 2011; Oyserman, 2015), while others were developed mainly inductively.

Once codes were identified, they were deductively applied to the interview data using a binary approach, where each sentence of participant reflection was coded for the occurrence (1) or non-occurrence (0) of each of the 12 identity-related codes. At this stage, all interview segments were randomized, and codes were applied blind to individuals and student/alumnus groups. Interrater agreement across two coders was reached using social moderation (Herrenkohl & Cornelius, 2013), during which researchers reconciled their codes line by line to address any discrepancies.

To understand differences in the ways that current Northeast AMP students and alumni conceptualized their processes of identity exploration and their possible future selves, we applied epistemic network analysis (ENA) (Shaffer, 2017). ENA is a quantitative ethnographic technique used to model the relationships between constructs in discourse that functions under the following assumptions: (a) that it is possible to systematically identify meaningful features in data (codes); (b) that the data have local structure (conversations); and (c) that an important feature of the data is the way that codes are connected to one another within conversations (Shaffer et al., 2016). ENA generates network visualizations of the co-occurrence of codes within a moving stanza window, which means that code connections are measured both when they co-occur in the same sentence, and also when codes are applied a few sentences from each other (in this case 3 sentences, as recommended by Siebert-Evenstone et al., 2017). This process is appropriate given

the conceptualization of identity exploration as a developmental process of change, where self-reflection in one moment builds upon prior conceptualizations of self iteratively over time.

To generate the epistemic networks, the units of analysis were set as the alumni and student groups, subset by each participant in the sample. Conversations were segmented by each interviewee and any breaks in their interview data (i.e., two parts of the interview between which off-topic discussion had been removed), to ensure that connections were not generated across student data or across statements made at different points in time. ENA compares the student and alumni networks simultaneously, so that they can be compared visually and statistically. Network comparisons can include tests of statistically significant difference between group means (student versus alumni), as well as numerical comparisons of the strength of associations between codes across models. For example, a connection strength of 0.4 in the student model would be twice as strong as a connection strength of 0.2 in the alumni model.

To identify the strength of associations between codes applied to the data, ENA creates a set of adjacency matrices, where each matrix represents, where codes co-occur across lines in a stanza (in this case, each line and the prior three lines of interview data per student to account for topical connections over time). Then, ENA sums the adjacency matrices to create a cumulative matrix, where each pair of codes co-occur. This is converted into an adjacency vector that exists in a high dimensional space, containing all unique co-occurrences of each code summed across all the data stanzas. Spherical normalization is then applied to the adjacency vectors to account for units of data that are different sizes (i.e., more or fewer lines of data from each interviewee), before a dimensional reduction is performed on the high-dimensional space using singular value decomposition. This process results in relative frequencies of co-occurrence between each code—what we call strength of associations (see Shaffer et al., 2016 for further detail). Nonparametric Mann–Whitney U tests (assuming non-normal data) were conducted to test whether differences between student and alumni discourse were statistically significant along the X-axis, as a means rotation was used to maximize variance along one axis. Network findings are supplemented with a discussion of the qualitative and thematic findings to help close the interpretive loop (Shaffer, 2016).

Results

The epistemic network model had co-registration correlations of 0.97 (Pearson) and 0.97 (Spearman) for the first dimension and co-registration correlations of 0.99 (Pearson) and 0.99 (Spearman) for the second. These measures indicate strong goodness of fit between the epistemic networks and the underlying patterns in the data. A nonparametric Mann–Whitney U test also showed that the alumni network (Mdn = 0.81, $n = 10$) was statistically significantly different (alpha < 0.05) from the student network (Mdn = −0.54, $n = 11$, $U = 108.00$, $p = 0.00$, $r = -0.96$), suggesting meaningful differences in their patterns of connection-making across identity themes in their interviews. This is an important point of illustration between studies addressing only current undergraduate students and those addressing the more nuanced undergraduate and alumni experiences in STEM.

Student identity exploration

Figure 1 shows the epistemic network of associations that students made across the 12 identity constructs over the course of their interviews. Student discourse was primarily driven by connections between the process of "taking action" and codes such as a "less certain future" self or role (0.24),[1] discussions of their "current interests" (0.17), discussions of a "future field" they hope to engage in (0.14), a specific "future career role" or job title they aspire to (0.13), and "current valuing of a topic" (0.11). A relatively robust connection also manifested between discussions of students' current interests and their current values in STEM (0.15).

A visual examination of the student model (Fig. 1) also reveals "taking action", "less certain future", "current interest" and "future career field" as more heavily connected constructs compared to other constructs in the network, suggesting an emphasis by current students on active action taking to explore their emerging interests in STEM without clear future career goals in mind. Interpretive examination of student data confirms a narrative pattern of student discourse, where they would first detail STEM-related steps they were taking as part of their major or academic program, and then follow-up with a discussion of general or "less-certain" roles for which these actions were intended. For example, one student alternated discussions of her current activities with potential, less-certain roles:

> Line 1: I was trying to do a gap year at [company name], best company, you know, they might have semiconductor research. (taking actions)

[1] The numbers in parentheses represent connection strengths between identity themes in the interview discourse, normalized across participant data.

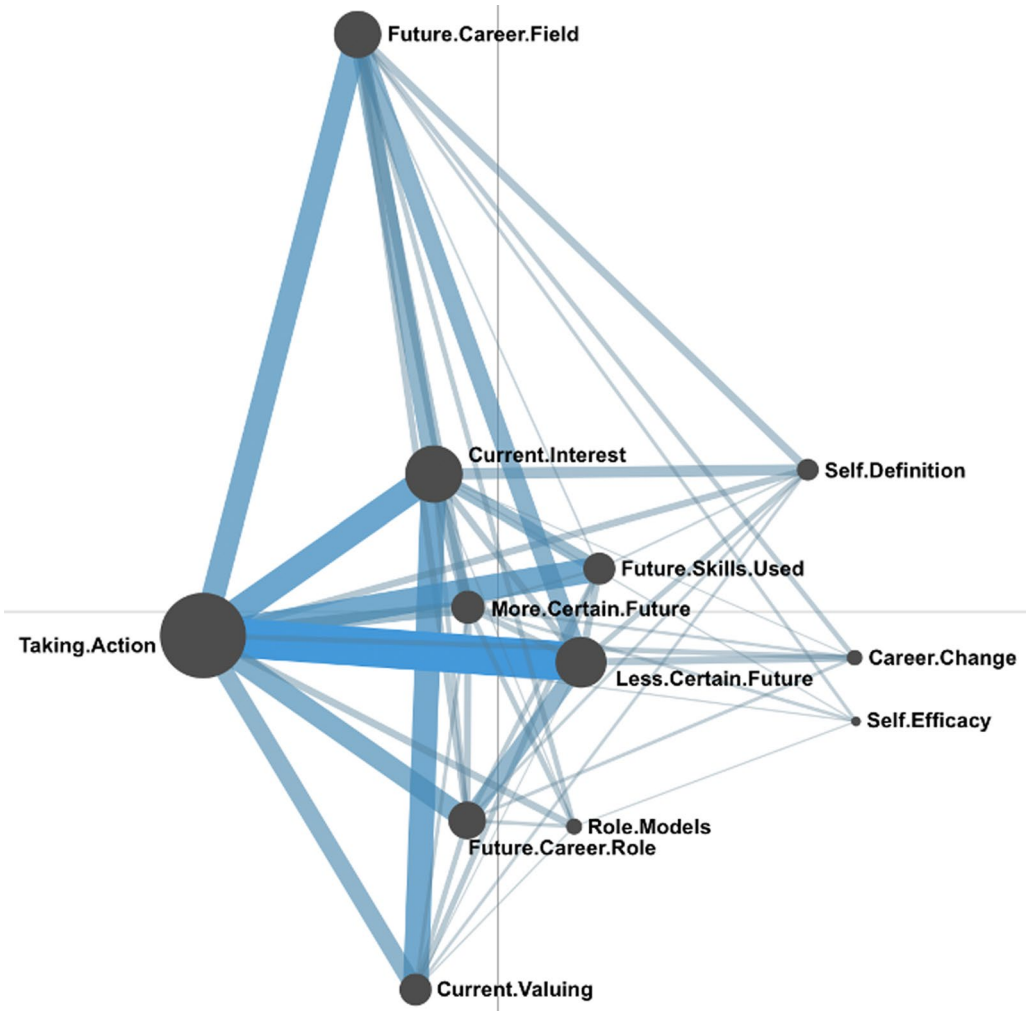

Fig. 1 Epistemic network of associations between identity themes for student interviews

> Line 2: This was going to depend on COVID you know kinda set all of this stuff, so you know I, I want to keep my options open. (less certain future)
> Line 3: I'm even considering, you know, working as a professor, and I recently participated in—what was it—a faculty exploration in [Northeast AMP location]. (less certain future, taking actions)
> Line 4: So yeah I kinda want to keep my options open. (less certain future)

Relationships between discussions of interests and taking action also represent taking action as a form of more open-ended explorations of multiple different roles or topical interests, such as the student who described looking for different research positions or jobs in biomimicry to satisfy her individual passion. In some cases, students knew that the experiences in which they engaged and the actions they took in the present were working toward future participation in a general STEM field but had not settled on a specific career or role. Others described taking actions to explore multiple potential career roles. As one student put it, "As far as what I want to do at the end of the program, honestly I'm not really sure. I'm hoping the program helps me figure it out."

These findings illustrate how engagement in STEM-focused programming at students' respective AMP-affiliated schools may have at least tacitly encouraged students to take actions to explore facets of different STEM interests and career fields, but that student conceptualizations of their future selves in STEM had often not coalesced around specific or concrete future roles or career titles. This pattern of open-ended STEM identity exploration was relatively consistent across different student reflections, suggesting a more uniform experience as they engaged in the exploration or possible future selves in STEM as supported by Northeast AMP. This narrative

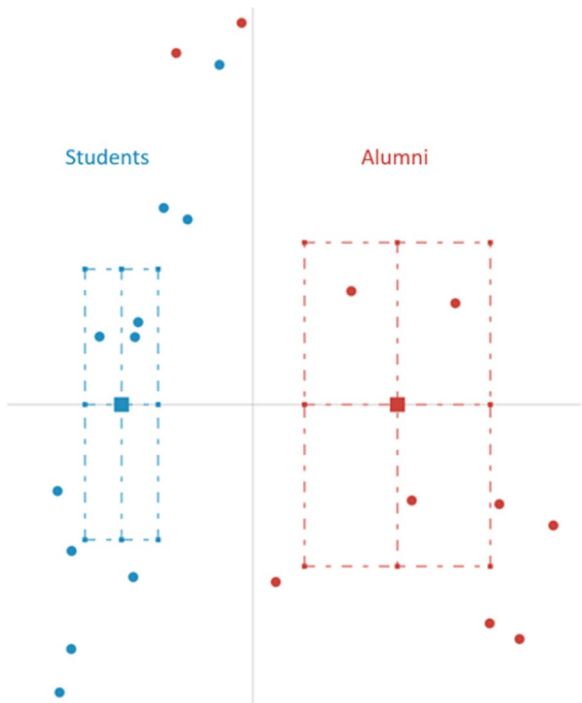

Fig. 2 Confidence intervals around network means (square) for participant units (circles)

consistency and clustering across student units in the sample is exemplified by the narrower confidence interval around the network mean (blue square) for students compared to the network mean for alumni (red square) (see Fig. 2).

X- and *Y*-axes for each model represent the boundaries of the high-dimensional space in which adjacency vectors are visualized and normalized. In this case, a means reduction was applied to maximize variance between student interviews (blue points) and alumni interviews (red points) along the *x*-axis. This view highlights the ways in which patterns of association between students and alumni are most separable. Student network means (blue points) are skewed left toward taking actions in the left quadrants, while alumni network means (red points) are dispersed across multiple quadrants, representing more diverse patterns of connection-making.

Alumni identity exploration

A visual inspection of the epistemic network for alumni discourse, on the other hand, reveals a more balanced pattern of association across a variety of identity themes represented in the model, rather than discourse centering around any single identity code (see Fig. 3). Similar to students, alumni regularly discussed their process of "taking action," but were more likely to connect this to discussions of self-efficacy (0.13) in their chosen STEM career. Alumni were also relatively likely to discuss a "less certain future" in terms of their careers and STEM identities, but were more likely to connect this to a discussion of the "future skills used," or the tasks or skills they hoped to leverage in future STEM roles (0.13), as well as to their "current interests" in STEM (0.12). Other slightly more robust connections in the alumni model included discussions of "taking action" in relation to descriptions of a "future career field" in which alumni hoped to work in the future (0.12). This suggests a possibility that compared to students at the beginning of their STEM pathway, as past URM program participants progressed in their individualized STEM career, they may feel less of a need for open-ended exploratory actions in STEM, since they may have already developed a more distinct understanding of their identities (e.g., what they like, what they are good at) as well as certain knowledge about the state of their specific STEM role or field (e.g., specific skills required moving forward).

Another way to interpret the alumni model is through a visual examination of the weighted size of each construct node, which shows "taking action," "less certain future," "self-definition," "future skills used," and "self-efficacy" as the most heavily connected constructs. Interpretive examination of alumni reflections confirmed that they were more likely to integrate a variety of different facets of their identity exploration processes in their interview discussions. In addition, reflection on possible future selves tended to be more diverse across alumni in the sample, with different participants making different connections in unique ways. Consider the wider confidence interval around the alumni network (red square) in Fig. 2, which suggests that unit means for alumni are less clustered and, therefore, more diverse in terms of their patterns of connection-making.

Compare the following interview examples from two alumni from different STEM roles:

> Line 1: But career goals… I would like anything that could pay me well and keep me using my engineering brain and my lawyer brain. (current valuing, self-definition, future skills used)
> Line 2: Even my LinkedIn says, I'm an engineer, I'm a lawyer and I'm a problem solver and I'm a critical thinker and that's what I want to do. (self-efficacy, self-definition)
> Line 3: It's kind of general, but so I've no plans on leaving my current employer unless I found like a better deal, like something that still allows me to do what I'm doing. (current valuing, future skills used, less certain future)

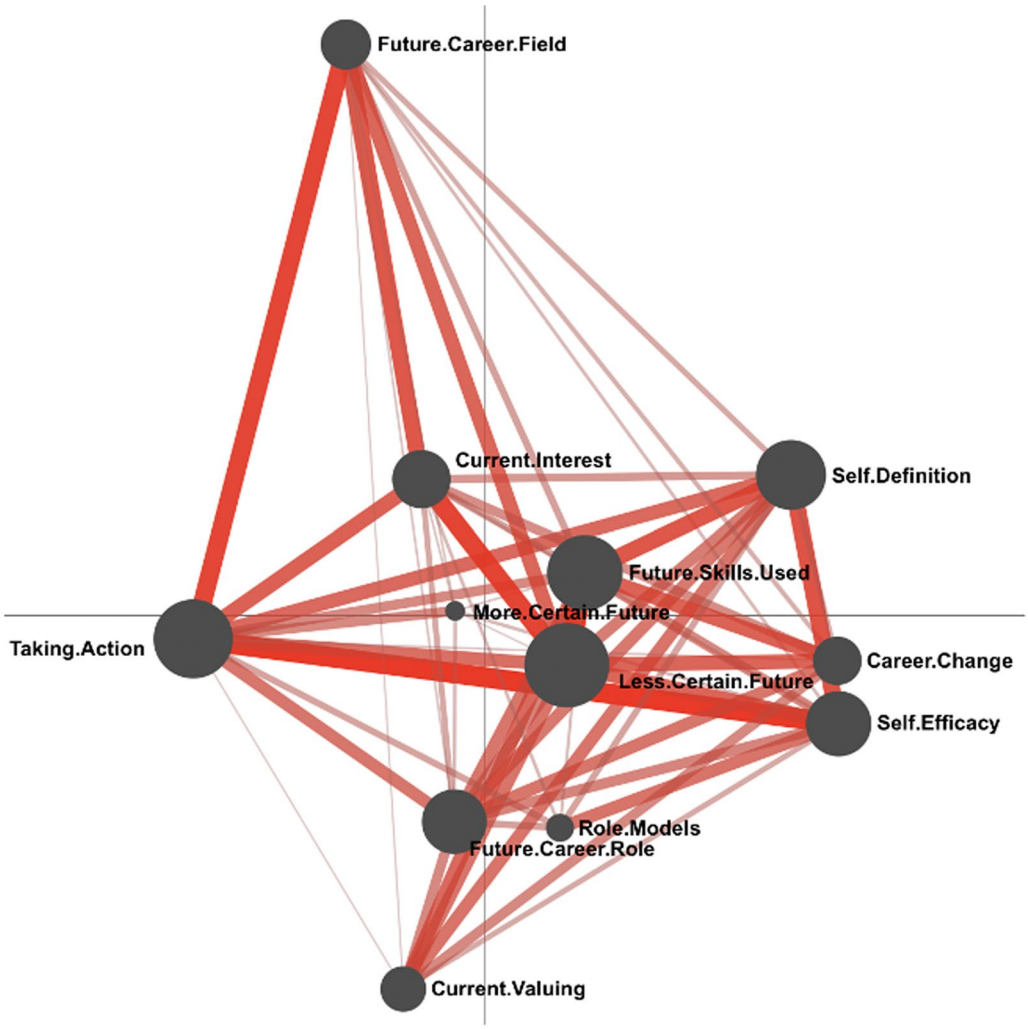

Fig. 3 Epistemic network of associations between identity themes for alumni interviews

Line 1: That [career] is a little bit more up in the air. (less certain future)
Line 2: I'm trying to get hired with a process or a scale-up commercialization sort of role, because I want primarily to be able to get a couple of years of industry experience. (taking action, future career role)
Line 3: Because the positions that I'm really looking at—so working with—let's say sustainability units within chemical manufacturers… (future career role)
Line 4: I've recently started to understand this space a little bit more, the startup space. (self-efficacy)

While both alumni reflected on a less-certain future and affirmed confidence in facets of their own knowledge and abilities (i.e., self-efficacy), the first alumna connected these themes to her current self-definition as a lawyer and engineer and her valuing of features in her current STEM job. The other alumnus connected these themes to his current actions and a specific desired future career he was working to attain. These findings suggest that not only are alumni discussions more likely to integrate a variety of different facets of the self in a more complex and detailed way, but that the pattern of reflection for each alumnus may be more thematically and conceptually distinct in terms of their socio-cultural situation: alumni 1 and 2 differ in terms of the specific job they currently have, their STEM experiences since graduation, the skills they use, and the amount of time that had passed, since they engaged in the Northeast AMP programming at their alma mater. Ultimately, these features place them not only on unique STEM career paths, but at different points in their STEM professional identity exploration.

Discussion

This work explores how minoritized students and alumni describe their identity exploration processes when asked to reflect on their possible future selves in STEM. Findings help to build on existing research on identity exploration processes to illustrate what and how URM learners and professionals in STEM connect to facets of their future possible selves. First, findings highlight the value of examining STEM identity exploration over time from the perspectives of URM learners themselves. Despite affirming more diverse and nebulous STEM interests, roles, and topics, students routinely connected these aspects of their STEM futures to their academic choices and processes in the present. This suggests that even students with a more exploratory or undetermined future in STEM are aware of how their current actions and perspectives play a valuable role in defining that future. This aligns with identity researchers such as Kaplan and colleagues' work (Flum & Kaplan, 2006; Kaplan et al., 2017, 2020) in their affirmation of identity *exploration* as a valuable part of twenty-first century success. In such cases, the URM self-authorship in STEM called for by Morton and Parsons (2018) is unfolding in intentional and targeted ways, underscoring the value and necessity of holistic university programs that promote identity exploration (Armstrong & Jovanovic, 2017).

This work also provided a valuable opportunity to interrogate theoretical conceptualizations of identity exploration through the lens of what URM AMP participants found relevant to their STEM professional and academic development. While inductive examination of the data revealed themes related to cognitive, affective, behavioral, and self-definitional aspects of the self (Foster, 2014), different themes may prove particularly relevant for intentional reflection at different points of URM learners lives and STEM careers. For example, students' emphasis on exploration of possible future selves through engagement with various STEM-related activities (taking action) aligns with previous scholarship (Burwell-Woo et al., 2015; Foster et al., 2019). The fact that students' active action-taking was heavily connected to their current interests in STEM also supports the key role of motivational factors such as personal interests in STEM participation (Gottlieb, 2018; Lv et al., 2022).

Other emergent factors such as influential others/role models (Atkins et al., 2020; Tey et al., 2020), self-definition/perception (Collins, 2018; Morton & Parsons, 2018) and self-efficacy (Jiang et al., 2020; Turner et al., 2022) were highlighted by past literature as important for students choosing and persisting in STEM. While close qualitative examination did reveal instances of reflection on these factors, they were not as strongly connected in the student ENA model. This is not to suggest that these elements are not influential to learner experience, but that they may not be experienced universally. Further school efforts to support and connect to these elements of identity may result in new identity exploration patterns, and potential improved outcomes for URM in STEM.

Alumni reflections revealed both more holistic and integrated discussions of self, with more unique career and context-specific discussions of their identity exploration processes seen in the overall more balanced network model for alumni (Fig. 3). This differs from the more uniform pattern of open-ended exploration featured in the student model. We hope that this examination of diversity of alumni reflections in our findings can further serve to contradict existing misconceptions of long-term URM professional pathways in STEM—both that there is only one valid pathway to STEM success (see Petray et al., 2019), and that meaningful exploration of a possible future self in STEM stops later in a learner's professional career. While alumni also highlighted a less certain future in some instances, this was less connected to discussions of their current actions, and more connected to future skills and current interests. Instead of the students' more preliminary exploration of possible future selves in STEM, alumni were more explicitly aware of their situated STEM interests and the skills they employ as they move forward in their careers.

Alumni reflections on possible future selves tended to be more diverse across the sample compared to students, meaning that different alumni make connections among identity constructs in more unique, complex ways. Qualitative interpretations of interview data suggest that alumni's reflecting on themselves, which diverged into more individualized patterns, may be related to their post-graduate experiences. Discourse findings across alumni may help to explain the 4-year drop-off in measured impact of school-supported interventions related to identity exploration in alumni published by Estrada and colleagues (2018). As alumni move further along their increasingly unique STEM trajectories post-graduation, they tend to develop socio-culturally distinct and contextually valid patterns of growth and self-reflection over time. As alumni become more immersed in specific careers, these socio-culturally situated contexts will shape their increasingly unique STEM trajectories and patterns of exploration over time.

Self-definition and self-efficacy were more prominent identity constructs when alumni reflected on their possible future selves, which differs from the student model. Given the shifting and unpredictable nature of the STEM workforce (Savickas et al., 2009), specific future career movements may be hard to predict for some alumni without more specific examination of their post-graduation

experiences. Nonetheless, most alumni in this situation can clearly identify what they want or care about in their STEM career, and what skills they will need to master to continue to succeed compared to their student peers, as seen in their more explicit discussions of the self in STEM. This does not indicate that those in STEM careers necessarily have more established STEM identities (Kelly et al., 2020); but that professionals tend to draw from knowledge of themselves and confidence in what they can achieve when envisioning a future in STEM. These findings also emphasize the importance of continued examination and support of later-career STEM identity exploration with URM alumni (Norman et al., 2021; Simpson & Bouhafa, 2020).

Implications

While this scholarship seeks to explore the complexities of identity exploration, and not to evaluate the efficacy of STEM minority programming, these exploratory findings nonetheless offer implications for practitioners aiming to encourage minority participation in STEM. First, students described a process of open-ended exploration of STEM roles, topics, and fields driven by current interests. Higher education programming can support this process by maximizing student exposure to broad and diverse STEM majors and career experiences (Hall et al., 2011) while promoting existing interests in STEM (Slovacek et al., 2019). Student-cited examples of such programming may include engagement with URM student organizations, co-op opportunities, early research exposure, mentorship, and career workshops. Second, this work reveals that participants' identity exploration processes grew increasingly specific to unique STEM contexts over time (Foster & Shah, 2021; Foster et al., 2019). To facilitate these long-term shifts, connection-making between current students and alumni/professionals through mentoring, networking, or guest-speaking events might prove valuable. These initiatives could contribute to students' open-ended exploration of STEM career paths by providing them with valuable insider information about the state of the field from the perspectives of alumni who also come from minoritized backgrounds.

Set in the context of Northeast AMP program as a STEM minority participation program, findings point to the reflective processes on possible future selves enacted by STEM novice and STEM professionals from a minority participation program as part of their identity exploration. While findings have implications for understanding and supporting these processes as discussed above, this research did not systematically establish any precise relationships between the identity exploration patterns and any one initiative or experience offered by Northeast AMP. Future work could examine how participation in different kinds of STEM minority programming may have differential or compounding impacts on identity exploration in the short and long term (e.g., funding versus peer mentorship, etc.).

The current study focuses on cross-group comparison between underrepresented STEM alumni and students at different stages of their majors and careers, but it does not explore the differences by institutional affiliation, STEM discipline, academic or career performance, or cross-group demographics. In-depth future research into the long-term patterns of identity exploration enacted by specific individuals, racial or cultural groups, employee cohorts, or specific STEM majors may help to parse out the unique patterns of connection-making in relation to possible future selves over time.

As a cross-sectional examination of participant self-reflections through a one-time interview, this work does not track how individual conceptualizations of possible future selves may evolve over time; this work instead examines how participants describe and conceptualize their own trajectories of change from past to possible future. Future works can track identity exploration processes of the same cohort of participants (within-group change) as they progress from college to the STEM workplace. Such a longitudinal approach bears merits as the next step for deepening theoretical understandings of long-term evolution of STEM identities in minoritized individuals, as well as the role of STEM minority program participation throughout the process.

Overall, this study contributes to research on STEM identity exploration and minority participation by highlighting patterns of connection-making enacted by past and current participants and suggesting how individual career journeys might differ post-graduation. The focus of this study moves beyond *current STEM identities* of students in school—as typically seen in identity-focused research—to *future identities* conceptualized by minoritized populations at different points along their STEM pathways. Through characterizing STEM identity exploration processes as related to possible future selves in minoritized students and alumni, this scholarship offers some program-level implications regarding supporting this newcomer-to-professional process in underrepresented populations as a way to further equity in STEM. By representing the alumni population, the study contributes to the limited scholarship on STEM identities at the professional level (Norman et al., 2021; Simpson & Bouhafa, 2020). This work also demonstrates the utility of quantitative ethnographic techniques such as epistemic networks for elucidating patterns of identity exploration in STEM, supported by in-depth, qualitative interpretations and thematic analysis. The grounded approach based on interview discourse sets this work different

from more structured survey/questionnaire design commonly used for longitudinal STEM identity exploration (e.g., Estrada et al., 2018; Hernandez et al., 2013; Park et al., 2018). Future work may extend the exploratory application of ENA in this study to larger student and alumni data sets or to secondary sources to understand identity exploration in these contexts with even greater nuance.

Conclusion

This work examines the conceptual patterns that emerge in interview discourse as present and past participants (students and alumni) of one STEM minority participation program reflected on their possible future selves in STEM and the extent to which patterns of thematic connection-making differ between participants at different stages within their STEM pathways. Informed by scholarship on identity research and identity exploration theory, the researchers employed inductive thematic coding of selected interview data and established epistemic network analysis models capturing themes surrounding possible future selves. The characterizations of students and alumni were achieved by measuring their model differences as well as interpretative examination of interview data. Results highlight the differences between novices' and professionals' conceptualizations of their future selves and highlight the unique ways they conceptualize their pursuit of STEM majors and careers in the past, present, and future. This work has implications for future STEM identity research and practice, including higher education programming as a tool to support students' STEM identity exploration processes.

Abbreviations

AMP	Alliance for Minority Participation
ENA	Epistemic Network Analysis
NSF	National Science Foundation
STEM	Science, Technology, Engineering, and Mathematics
URM	Underrepresented Minority

Acknowledgements

We thank graduate research assistants of the Lab for their contribution toward data collection and processing that laid a foundation for this work. We extend a debt of gratitude to the epistemic analytics group at the University of Wisconsin-Madison for the development of the network analysis tool that was used in this project (DRL-1661036, DRL-1713110, DRL-2100320).

Author contributions

The corresponding author conceptualized the aims and research questions for this work, conducted the literature review, curated the final data set, and collaborated in data analysis and conceptualization of results. Author two oversaw development of the research aims, literature review, and data set curation. The author collaborated in data analysis and the conceptualization of results. Author three is the principal investigator (PI) for the NSF research grant supporting this work. The author developed the overarching study aims, study design, and data collection from which this data set and research study were derived and supervised the development of this specific research inquiry. All authors read and approved the final manuscript.

Funding

This work is supported by the National Science Foundation (2008197).

Availability of data and materials

The data that support the findings of this study are not openly available due to privacy concerns (i.e., human subject data that are subject to Institutional Research Board guidelines). A sample of the de-identified data are available from the corresponding author upon reasonable request in a controlled access repository where relevant.

Declarations

Competing interests

The authors declare that they have no competing interests.

Received: 26 July 2022 Accepted: 3 March 2023
Published online: 20 March 2023

References

Andrist, S., Collier, W., Gleicher, M., Mutlu, B., & Shaffer, D. (2015). Look together: Analyzing gaze coordination with epistemic network analysis. *Frontiers in Psychology, 6*, 1016.

Atkins, K., Dougan, B. M., Dromgold-Sermen, M. S., Potter, H., Sathy, V., & Panter, A. T. (2020). "Looking at Myself in the Future": How mentoring shapes scientific identity for STEM students from underrepresented groups. *International Journal of STEM Education, 7*(1), 1–15.

Alfred, M. V., Ray, S. M., & Johnson, M. A. (2019). Advancing women of color in STEM: An imperative for US global competitiveness. *Advances in Developing Human Resources, 21*(1), 114–132.

Allen, C. D., & Eisenhart, M. (2017). Fighting for desired versions of a future self: How young women negotiated STEM-related identities in the discursive landscape of educational opportunity. *Journal of the Learning Sciences, 26*(3), 407–436.

Ainley, M., & Ainley, J. (2011). A cultural perspective on the structure of student interest in science. *International Journal of Science Education, 33*(1), 51–71.

Apple, M. T., Falout, J., & Hill, G. (2020). The relationship between future career self images and English achievement test scores of Japanese STEM students. *IEEE Transactions on Professional Communication, 63*(4), 372–385.

Armstrong, M. A., & Jovanovic, J. (2017). The intersectional matrix: Rethinking institutional change for URM women in STEM. *Journal of Diversity in Higher Education, 10*(3), 216.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191–215.

Bandura, A. (1986). The explanatory and predictive scope of self-efficacy theory. *Journal of Clinical and Social Psychology, 4*, 359–373.

Barany, A., & Foster, A. (2021). Context, community, and the individual: Modeling identity in a game affinity space. *The Journal of Experimental Education, 89*(3), 523–540.

Belser, C. T., Shillingford, M., Daire, A. P., Prescod, D. J., & Dagley, M. A. (2018). Factors influencing undergraduate student retention in STEM majors: Career development, math ability, and demographics. *Professional Counselor, 8*(3), 262–276.

Blotnicky, K. A., Franz-Odendaal, T., French, F., & Joy, P. (2018). A study of the correlation between STEM career knowledge, mathematics self-efficacy, career interests, and career activities on the likelihood of pursuing a STEM career among middle school students. *International Journal of STEM Education, 5*(1), 1–15.

Burrell, D. N. (2020). An exploration of the cybersecurity workforce shortage. *Cyber warfare and terrorism: Concepts, methodologies, tools, and applications* (pp. 1072–1081). IGI Global.

Burwell-Woo, C., Lapuz, R., Huang, T., & Langhoff, N. (2015, June). Enhancing Knowledge, Interest, and Self-Efficacy in STEM Through a Summer STEM Exploration Program. In *2015 ASEE Annual Conference & Exposition* (pp. 26–660).

Byars-Winston, A. (2014). Toward a framework for multicultural STEM-focused career interventions. *The Career Development Quarterly, 62*(4), 340–357.

Camilli, G., & Hira, R. (2019). Introduction to special issue—STEM workforce: STEM education and the post-scientific society. *Journal of Science Education and Technology, 28*(1), 1–8.

Castellanos, M. (2018). Examining Latinas' STEM career decision-making process: A psycho sociocultural approach. *The Journal of Higher Education, 89*(4), 527–552.

Collins, K. H. (2018). Confronting color-blind STEM talent development: Toward a contextual model for Black student STEM identity. *Journal of Advanced Academics, 29*(2), 143–168.

Crawford, M. B., Wilson-Kennedy, Z. S., Thomas, G. A., Gilman, S. D., & Warner, I. M. (2018). LA-STEM Research Scholars Program: A model for broadening diversity in STEM education. *Technology & Innovation, 19*(3), 577–592.

Creswell, J. W. (2015). *Educational research: Planning, conducting and evaluating quantitative and qualitative research* (4th ed.). Pearson.

Destin, M., & Williams, J. L. (2020). The connection between student identities and outcomes related to academic persistence. *Annual Review of Developmental Psychology, 2*, 437–460.

Doerschuk, P., Bahrim, C., Daniel, J., Kruger, J., Mann, J., & Martin, C. (2016). Closing the gaps and filling the STEM pipeline: A multidisciplinary approach. *Journal of Science Education and Technology, 25*(4), 682–695.

Dunlosky, J., & Ariel, R. (2011). Self-regulated learning and the allocation of study time. *Psychology of Learning and Motivation, 54*, 103–140.

Duran, A., & Jones, S. R. (2020). Complicating identity exploration: An intersectional grounded theory centering queer students of color at historically white institutions. *Journal of College Student Development, 61*(3), 281–298.

Elmoazen, R., Saqr, M., Tedre, M., & Hirsto, L. (2022). A systematic literature review of empirical research on epistemic network analysis in education. IEEE Access.

Ely, R. J., & Thomas, D. A. (2020). Getting serious about diversity. *Harvard Business Review, 98*(6), 114–122.

Erikson, E. H. (1959). *Identity and the life cycle: Selected papers.* International Universities Press.

Estrada, M., Hernandez, P. R., & Schultz, P. W. (2018). A longitudinal study of how quality mentorship and research experience integrate underrepresented minorities into STEM careers. *CBE—Life Sciences Education, 17*(1), ar9.

Fan, Y., Barany, A., Foster, A. (2022, June). *Future selves in STEM: An epistemic network analysis of past and present STEM minority program participants* [Paper presentation]. International Conference on Learning Sciences, Hiroshima, Japan.

Fayer, S., Lacey, A., & Watson, A. (2017). *STEM occupations: Past, present, and future.* US Bureau of Labor Statistics.

Flum, H., & Kaplan, A. (2006). Exploratory orientation as an educational goal. *Educational Psychologist, 41*(2), 99–110.

Foster, A. (2014). *CAREER: Projective reflection: Learning as identity exploration within games for science*. Drexel University.

Foster, A., Shah, M., Barany, A., & Talafian, H. (2019). High school students' role-playing for identity exploration: Findings from virtual city planning. *Information and Learning Sciences, 120*(9/10), 640–662.

Foster, A., & Shah, M. (2021). Framing and studying learning and identity in virtual learning environments: Introduction to the special issue. *The Journal of Experimental Education, 89*(3), 445–449.

Gasman, M., Nguyen, T. H., Conrad, C. F., Lundberg, T., & Commodore, F. (2017). Black male success in STEM: A case study of Morehouse College. *Journal of Diversity in Higher Education, 10*(2), 181.

Goff, E. E., Mulvey, K. L., Irvin, M. J., & Hartstone-Rose, A. (2020). The effects of prior informal science and math experiences on undergraduate stem identity. *Research in Science & Technological Education, 38*(3), 272–288.

Gottlieb, J. J. (2018). STEM career aspirations in Black, Hispanic, and White ninth-grade students. *Journal of Research in Science Teaching, 55*(10), 1365–1392.

Grossman, J. M., & Porche, M. V. (2014). Perceived gender and racial/ethnic barriers to STEM success. *Urban Education, 49*(6), 698–727.

Habig, B., Gupta, P., Levine, B., & Adams, J. (2020). An informal science education program's impact on STEM major and STEM career outcomes. *Research in Science Education, 50*(3), 1051–1074.

Hall, C., Dickerson, J., Batts, D., Kauffmann, P., & Bosse, M. (2011). Are we missing opportunities to encourage interest in STEM fields? *Journal of Technology Education, 23*(1), 32–46.

Hernandez, P. R., Schultz, P., Estrada, M., Woodcock, A., & Chance, R. C. (2013). Sustaining optimal motivation: A longitudinal analysis of interventions to broaden participation of underrepresented students in STEM. *Journal of Educational Psychology, 105*(1), 89.

Herrenkohl, L. R., & Cornelius, L. (2013). Investigating elementary students' scientific and historical argumentation. *Journal of the Learning Sciences, 22*(3), 413–461.

Ho, M. T., La, V. P., Nguyen, M. H., Pham, T. H., Vuong, T. T., Vuong, H. M., & Vuong, Q. H. (2020). An analytical view on STEM education and outcomes: Examples of the social gap and gender disparity in Vietnam. *Children and Youth Services Review, 119*, 105650.

Hotle, S. L., & Katz, B. J. (2018). Decision support for civil engineering students: Analysis of alumni career paths. *Transportation Research Record, 2672*(13), 1–9.

Jelks, S. M., & Crain, A. M. (2020). Sticking with STEM: Understanding STEM career persistence among STEM bachelor's degree holders. *The Journal of Higher Education, 91*(5), 805–831.

Jiang, S., Simpkins, S. D., & Eccles, J. S. (2020). Individuals' math and science motivation and their subsequent STEM choices and achievement in high school and college: A longitudinal study of gender and college generation status differences. *Developmental Psychology, 56*(11), 2137.

Kaliisa, R., Misiejuk, K., Irgens, G. A., & Misfeldt, M. (2021, February). Scoping the emerging field of quantitative ethnography: opportunities, challenges and future directions. In *International Conference on Quantitative Ethnography* (pp. 3–17). Springer.

Kang, H., Calabrese Barton, A., Tan, E., Simpkins, D., & S., Rhee, H. Y., & Turner, C. (2019). How do middle school girls of color develop STEM identities? Middle school girls' participation in science activities and identification with STEM careers. *Science Education, 103*(2), 418–439.

Kaplan, A., Bridgelal, I., & Garner, J. K. (2020). Sociocultural processes in identity-based motivational interventions: A dynamic systems perspective. In G. Liem & D. McInerney (Eds), *Promoting learning and motivation in contexts: Sociocultural perspectives on educational interventions.* Information Age Publishing, 83–114.

Kaplan, A., & Garner, J. K. (2017). A complex dynamic systems perspective on identity and its development: The dynamic systems model of role identity. *Developmental Psychology, 53*(11), 2036.

Kelly, R., Garr, O. M., Leahy, K., & Goos, M. (2020). An investigation of university students and professionals' professional STEM identity status. *Journal of Science Education and Technology, 29*(4), 536–546.

Kim, A. Y., Sinatra, G. M., & Seyranian, V. (2018). Developing a STEM identity among young women: A social identity perspective. *Review of Educational Research, 88*(4), 589–625.

López-Aguirre, C. (2019). Women in Latin American science: gender parity in the twenty-first century and prospects for a post-war Colombia. *Tapuya: Latin American Science, Technology and Society, 2*(1), 356–377.

Lv, B., Wang, J., Zheng, Y., Peng, X., & Ping, X. (2022). Gender differences in high school students' STEM career expectations: An analysis based on multi-group structural equation model. *Journal of Research in Science Teaching., 59*, 1739.

Mappen, E. F. (2011). A review of the literature on increasing the representation of women undergraduates in stem disciplines through civic engagement pedagogies. *Science Education and Civic Engagement, 3*(1), 36.

Marcia, J. E. (1966). Development and validation of ego-identity status. *Journal of Personality and Social Psychology, 3*(5), 551–558.

Marco-Bujosa, L. M., Joy, L., & Sorrentino, R. (2020). Nevertheless, she persisted: A comparison of male and female experiences in community college STEM programs. *Community College Journal of Research and Practice, 7*, 1–19.

Markus, H., & Nurius, P. (1986). Possible selves. *American Psychologist, 41*(9), 954–969.

Martin-Hansen, L. (2018). Examining ways to meaningfully support students in STEM. *International Journal of STEM Education, 5*(1), 1–6.

McGee, E. O. (2020). Interrogating structural racism in STEM higher education. *Educational Researcher, 49*(9), 633–644.

Miller, K., Sonnert, G., & Sadler, P. (2018). The influence of students' participation in STEM competitions on their interest in STEM careers. *International Journal of Science Education, Part B, 8*(2), 95–114.

Morton, T. R., & Parsons, E. C. (2018). # BlackGirlMagic: The identity conceptualization of Black women in undergraduate STEM education. *Science Education, 102*(6), 1363–1393.

Murcia, K., Pepper, C., & Williams, J. (2020). Youth STEM career choices: What's influencing secondary students' decision making. *Issues in Educational Research, 30*(2), 593–611.
Nasir, N. I. S., & Hand, V. (2008). From the court to the classroom: Opportunities for engagement, learning, and identity in basketball and classroom mathematics. *The Journal of the Learning Sciences, 17*(2), 143–179.
Nasir, N. S., Rosebery, A. S., Warren, B., & Lee, C. D. (2006). Learning as a cultural process: Achieving equity Through Diversity. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 489–504). Cambridge University Press.
Nithithanatchinnapat, B., & Joshi, K. D. (2019). A global view of what fixes information technology skills shortage: Panel data analyses of countries' human and technology resources. *Journal of Global Business Insights, 4*(1), 59–77.
Norman, O., Pinder, P. J., Shelley, M. C., Harven, A., & Nkusi, M. (2021). The salience of identity in the academic success of black STEM students and professionals. *Leadership and Policy Quarterly, 10*(1–4), 1–16.
Ortiz, N. A., Morton, T. R., Miles, M. L., & Roby, R. S. (2019). What about us? Exploring the challenges and sources of support influencing black students' STEM identity development in postsecondary education. *Journal of Negro Education, 88*(3), 311–326.
Oyserman, D. (2015). *Pathways to success through identity-based motivation*. Oxford University Press.
Oyserman, D., & James, L. (2011). Possible identities. In S. J. Schwartz, K. Luyckx, & V. L. Vignoles (Eds.), *Handbook of identity theory and research* (pp. 117–145). Springer Science + Business Media.
Park, C. L., Williams, M. K., Hernandez, P. R., Agocha, V. B., Carney, L. M., DePetris, A. E., & Lee, S. Y. (2019). Self-regulation and STEM persistence in minority and non-minority students across the first year of college. *Social Psychology of Education, 22*(1), 91–112.
Payton, F. C., & Berki, E. (2019). Countering the negative image of women in computing. *Communications of the ACM, 62*(5), 56–63.
Petray, T., Doyle, T., Howard, E., Morgan, R., & Harrison, R. (2019). Re-engineering the" leaky pipeline" metaphor: Diversifying the pool by teaching STEM" by stealth". *International Journal of Gender, Science and Technology, 11*, 10–29.
Phelps, L. A., Camburn, E. M., & Min, S. (2018). Choosing STEM college majors: Exploring the role of pre-college engineering courses. *Journal of Pre-College Engineering Education Research, 8*(1), 1.
Price, C. A., Kares, F., & Segovia, G. (2016, June). *Gender differences in STEM career and educational choices of alumni of an urban, museum-based after-school program* [Poster Presentation]. 12th International Conference of the Learning Sciences, Singapore.
Renninger, K. A., & Hidi, S. E. (2015). *The power of interest for motivation and engagement*. Routledge.
Rincon, B. E., & George-Jackson, C. E. (2016). STEM intervention programs: Funding practices and challenges. *Studies in Higher Education, 41*(3), 429–444.
Ro, H. K., Fernandez, F., & Alcott, B. (2021). A comprehensive approach to addressing gender equity in STEM subjects at four-year universities in England. In H. K. Ro, F. Fernandez, & E. J. Ramon (Eds.), *Gender equity in STEM in higher education* (pp. 85–101). Routledge.
Ross, M., Capobianco, B. M., & Godwin, A. (2017). Repositioning race, gender, and role identity formation for Black women in engineering. *Journal of Women and Minorities in Science and Engineering, 23*(1), 89.
Rottinghaus, P. J., Falk, N. A., & Park, C. J. (2018). Career assessment and counseling for STEM: A critical review. *The Career Development Quarterly, 66*(1), 2–34.
Savickas, M. L., Nota, L., Rossier, J., Dauwalder, J. P., Duarte, M. E., Guichard, J., & Van Vianen, A. E. (2009). Life designing: A paradigm for career construction in the 21st century. *Journal of Vocational Behavior, 75*(3), 239–250.
Seidman, I. (2019). *Interviewing as qualitative research: A guide for researchers in education and the social sciences*. New York: Teachers College Press.
Seyranian, V., Madva, A., Duong, N., Abramzon, N., Tibbetts, Y., & Harackiewicz, J. M. (2018). The longitudinal effects of STEM identity and gender on flourishing and achievement in college physics. *International Journal of STEM Education, 5*(1), 1–14.
Shaffer, D. W. (2018). Epistemic network analysis: Understanding learning by using big data for thick description. in *International handbook of the learning sciences*, pp. 520–531.
Shaffer, D. W., Collier, W., & Ruis, A. R. (2016). A tutorial on epistemic network analysis: Analyzing the structure of connections in cognitive, social, and interaction data. *Journal of Learning Analytics, 3*(3), 9–45.
Shaffer, D. W. (2017). *Quantitative ethnography*. Cathcart Press.
Siebert-Evenstone, A., Arastoopour Irgens, G., Collier, W., Swiecki, Z., Ruis, A. R., & Shaffer, D. W. (2017). In search of conversational grain size: Modelling semantic structure using moving stanza windows. *Journal of Learning Analytics, 4*(3), 123–139.
Silver, C., & Lewins, A. (2014). *Using software in qualitative research: A step-by-step guide*. SAGE Publications.
Simpson, A., & Bouhafa, Y. (2020). Youths' and adults' identity in STEM: A systematic literature review. *Journal for STEM Education Research, 3*(2), 167–194.
Slovacek, S., Miu, V., Soto, K., & Ye, H. (2019). Supporting STEM in higher education. *International Journal of Education and Practice, 7*(4), 438–449.
Smith, A., & García, H. A. (2018). Increasing the trickle: A proposed critical multiculturalist conceptual model to increase the pipeline to a more diverse STEM doctorate population. *Journal for Multicultural Education, 12*(3), 206–220.
Steinke, J. (2017). Adolescent girls' STEM identity formation and media images of STEM professionals: Considering the influence of contextual cues. *Frontiers in Psychology, 8*, 716.
Syed, M., Zurbriggen, E. L., Chemers, M. M., Goza, B. K., Bearman, S., Crosby, F. J., & Morgan, E. M. (2019). The role of self-efficacy and identity in mediating the effects of STEM support experiences. *Analyses of Social Issues and Public Policy, 19*(1), 7.
Tey, T. C. Y., Moses, P., & Cheah, P. K. (2020). Teacher, parental and friend influences on STEM interest and career choice intention. *Issues in Educational Research, 30*(4), 1558–1575.
Timms, M. J., Moyle, K., Weldon, P. R., & Mitchell, P. (2018). *Challenges in STEM learning in Australian schools: Literature and policy review.* Australian Council for Educational Research (ACER). https://research.acer.edu.au/policy_analysis_misc/28
Turner, S. L., McWhirter, E. H., Lee, H., Mason-Chagil, G., Smith, S., Jacobs, S. C., & Jackson, A. P. (2022). Barriers to STEM efficacy and outcome expectations among Native American college students. *The Counseling Psychologist, 50*(7), 981–1008.
Verdín, D., Godwin, A., Sonnert, G., & Sadler, P. M. (2018, October). *Understanding how first-generation college students' out-of-school experiences, physics and STEM identities relate to engineering possible selves and certainty of career path*. IEEE Frontiers in Education Conference (pp. 1–8). IEEE.
Wortham, S. (2006). Learning identity: The joint emergence of social identification and academic learning. Cambridge University Press.

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