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Oh, the places you can go … if you ace calculus: helping minoritized students succeed in undergraduate mathematics

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Minoritized students tend to have lower undergraduate degree attainment in science, technology, engineering, and mathematics (STEM) than their White and South and East Asian counterparts. According to the Phenomenological Variant of Ecological Systems Theory (PVEST), factors related to historical contexts, systemic processes, and the individual interact to lead to underrepresentation in STEM. However, most of the literature on minoritized STEM students uses a deficit lens and does not consider the role of historical and systemic contexts on these students' STEM achievement. As a product, current interventions used to increase academic achievement are limited in scope and do not consider the complex interplay between the numerous factors known to influence academic success. By using PVEST as a framework, more holistic interventions that focus on minoritized STEM students' potential for success can be developed.

KEYWORDS

STEM, minoritized students, supports, collaborative learning, math anxiety, motivation, undergraduates, PVEST

Introduction

In the United States, Black, Latinx, Pacific Islander, Southeast Asian, and American Indian/Alaska Native students are minoritized[1] in science (excluding social and behavioral sciences), technology, engineering, and mathematics (STEM) majors compared to their White and other Asian counterparts (Arcidiacono et al., 2012; Bailey, 1990; Chavous and Drotar, 2016; Musu-Gillette et al., 2017; Oakes, 1990; Powell, 1990; Tsui, 2007; Whitcomb and Singh, 2021; Yu et al., 2016). For example, African American students are less likely than their White counterparts to pursue majors in STEM disciplines, opting instead to study humanities and/or social/behavioral sciences subject matters (Chavous and Drotar, 2016; Powell, 1990; Tsui, 2007).

According to the 2011/2012 cohort of the National Center for Education Statistics (NCES) study on Beginning Postsecondary Students,[2] 56.8% of postsecondary students were White, 14.1% Black/African American, 18.9% Hispanic, and 5.2% Asian. However, for those enrolled in STEM majors (not including social and behavioral sciences), 58% were White, 10.8% Black/

1 The term minoritized is used to discuss populations that have been historically excluded.
2 https://nces.ed.gov/surveys/bps/

African American, 15.2% Hispanic, and 9.9% Asian. This discrepancy demonstrates the notably lower representation of minoritized students, particularly Black and Hispanic students in STEM fields. Minoritized student representation decreases further when examining who attained a STEM bachelor's degree by 2017, with 62.7% being White, 6.2% Black/African American, 11.3% Hispanic, and 14.9% Asian. Most minoritized STEM students are lost to non-STEM majors, however, many will leave the institution without completing a degree (Arcidiacono et al., 2012; Chen, 2013; Riegle-Crumb et al., 2019). Chen (2013) found that 28% of all entering STEM students in their sample switched to non-STEM fields, whereas 20% left the institution without completing a degree. In contrast, 38% of Black entering STEM students switched to non-STEM fields and 29% left the institution without completing a degree.

The central goal of this paper is to apply a holistic identity-based developmental framework to review and evaluate the landscape of interventions that target minoritized students' STEM success in gateway math courses. The Phenomenological Variant of Ecological Systems Theory (PVEST) is applied to this review because it considers the complex contexts of these students and their individual differences. First, PVEST is leveraged to explain how minoritized students' STEM experiences and success are a consequence of how the university context interacts with students' backgrounds, identities, and perceptions. Second, this paper reviews some of the current interventions that could address different obstacles that minoritized students face in their STEM gateway math courses. Specifically, the review of the literature illustrates how these interventions, if implemented with consideration for students' identity and developmental needs, as outlined in PVEST, could be a first step for increasing minoritized students' STEM success.

Why does racial underrepresentation in STEM contexts persist?

Difficulties in early undergraduate coursework influence minoritized students' decisions to leave STEM majors. Astorne-Figari and Speer (2019) found that low GPAs in the first 2 years of undergraduate studies predict leaving STEM majors, and a major part of these first 2 years are gateway mathematics courses (Hagman, 2019). Mastering gateway mathematics courses is imperative for success in STEM (Ellis et al., 2016; Kokkelenberg and Sinha, 2010; Hagman, 2019). However, minoritized students tend to have higher D, F, and W (withdrawal) rates in calculus and university algebra courses than their White peers (Weston et al., 2019).

Lack of adequate K-12 STEM preparation is not a primary reason for the underrepresentation of minoritized students in STEM degree attainment (Thiry, 2019). Instead, undergraduate institutions have failed to provide environments for minoritized STEM students to thrive, particularly in gateway math courses. Several factors explain why minoritized students are underrepresented as STEM graduates. Some of these factors are unique to minoritized students (e.g., stereotype threat, experiences with racial discrimination, negative institutional/departmental racial climate, and cultural mismatch between the institution and the individual's values; Beasley and Fischer, 2012; Johnson et al., 2011; Maltese and Tai, 2011; McGee, 2020; Park et al., 2020; Ridgeway and McGee, 2018; Stephens et al., 2012). Other factors can be experienced by minoritized and majority group members but may interact with those minoritized student specific factors to pose additional burdens (e.g., loss of motivation, math anxiety, "weed out" culture, and lack of academic support; Hembree, 1990; Seymour and Hewitt, 1997; Weston et al., 2019). According to Seymour and Hewitt (1997), "responsibility for inadequate program support for students of color rests squarely on the shoulders of the institution," (p. 329). One reason institutions have not been successful at substantially increasing minoritized STEM student success in gateway courses, and by extension degree completion, is the limited scope of current intervention approaches (Museus, 2014; Tinto, 2012). Most interventions either focus on changing specific psychological factors of the student (e.g., motivation, stereotype threat, and math anxiety) or creating groups for minoritized students to connect with one another (e.g., collaborative learning programs). These interventions are generally implemented in isolation from one another without much consideration of how each program targets a different aspect of minoritized STEM student experiences (cite).

Most importantly, the way current interventions are developed and applied does not consider the greater historical and sociocultural context of minoritized STEM students. This is reflected in the fact that these programs mostly: (1) arise from deficit approaches and (2) treat minoritized students as a monolith. Deficit approaches ignore the obvious impact of external forces, such as a history of exclusion, current-day racism, and lack of representation, on the individual (Zengilowski et al., 2023). Intervention programs often focus on how individual students are lacking in skills, preparedness, or motivation. Such programs also tend to follow a one-size-fits-all all approach or monolith; however, everyone represents an intersection of identities, has varied strengths and weaknesses, and has had different experiences based on these contexts. Additionally, many interventions focus on how students are lacking in preparedness or motivation, rather than intervening on external forces that create barriers. For programs to successfully support undergraduate minoritized STEM students' success, they need to incorporate a holistic organizing framework that uses an asset-based approach and acknowledges the heterogeneity of racially minoritized communities.

Contextualizing minoritized students' STEM experiences using the phenomenological variant of the ecological systems theory

The phenomenological variant of ecological systems theory (PVEST) offers such a framework. PVEST states that an individual's external context (historical exclusion, culture, and family, etc.) informs their strengths, weaknesses, perceptions of past experiences, beliefs, values, coping, and identity, which in turn, shape their future plans and goal attainment (Spencer et al., 1997). One key contribution of PVEST is the premise that identity development is informed by the interaction between the socio-historical/chronological system in which students are situated and students' perceptions, a view that has been greatly lacking in the mainstream educational psychology and STEM education literature (Museus, 2014; Ridgeway and McGee, 2018).

PVEST offers a potential way to organize and understand how these numerous factors interact to impact minoritized students' outcomes in STEM. PVEST explains *how* and *why* distinct factors interact to influence the decisions of individuals (Spencer et al., 1997). This allows for a better understanding of the role of context (e.g., social, cultural, political, and historical landscape) on an individual's perceptions and behaviors (Spencer, 2006). This framework is ideal since it can account for the multiple overlapping contexts and experiences of individuals.

Based on Bronfenbrenner's ecological systems theory (Bronfenbrenner, 1977), PVEST describes how adolescents' "meaning making" or phenomenology of various ecosystems shapes their identity development (Spencer, 2006; Spencer et al., 2019). Educational psychologists describe identity as an individual's self-perceptions related to the following questions: "Who am I?" and "Am I capable?"(Usher, 2018, p. 135). Dupree et al. (2015) note, "identity processes are the mechanism through which children and adolescents internalize and sustain culturally informed adaptations to day-to-day, racialized challenges," (p. 117). Identity can relate to any type of self-perception, whether it be related to one's ethnic, racial, gender, sexual identity in-group, or in relation to domains of activity such as academics, mathematics, or science. For instance, educational researchers have defined mathematics identities as "the dispositions and deeply held beliefs that students develop about their ability to participate and perform effectively in mathematical contexts and to use mathematics in powerful ways across the contexts of their lives," (Aguirre et al., 2017, p. 14). Scholars have found that similar definitions apply to other STEM identities (e.g., engineering; see Godwin et al., 2020). Thus, PVEST allows scholars to consider identity development in a holistic sense. In relation to the current study, we were interested in considering how identity development is central to students' successful navigation of STEM majors (Carlone and Johnson, 2007; Godwin et al., 2020; Morton and Parsons, 2018; Hazari et al., 2010). We aim to use PVEST to help explain how math/STEM identities are developed alongside other identities, such as ethnic-racial identities, within students' family, school, and community contexts.

PVEST describes the "how" of identity development (i.e., how individuals perceive and respond to their stage-specific setting), and this process consists of five reciprocal components: (1) Net Vulnerability, (2) Net Stress (or Net Stress Engagement), (3) Reactive Coping Responses, (4) Emergent Identities, and (5) Stage-Specific Coping Outcomes (Spencer, 2006). Net Vulnerability consists of all the inevitable risk and protective factors in an individual's external context (e.g., socio-historical, societal, community, and family), as well as in their pre-existing stable personal attributes (e.g., values, beliefs, and tendencies). Net Stress is the cumulative influence of an individual's phenomenology of their Net Vulnerability. Importantly, Net Vulnerability is what makes an individual susceptible to stress, while Net Stress Engagement is the stress they actually face/feel. Reactive Coping Responses are the beliefs and behaviors that arise to cope with the individual's Net Stress. Emergent Identities are the individual's self-perceptions regarding their group membership and the internalization of the stable coping patterns associated with such self-perceptions. Lastly, Stage-Specific Coping Outcomes are the future patterns of responses of the individual in various potential contexts.

Prior literature employing the PVEST framework frequently centers on understanding the relationships between risk and protective factors (Net Vulnerability) and how students' experiences of stress (Net Stress Engagement) interact with their responses in a given context (Reactive Coping Strategy) to predict positive Emergent Identity and Stage Specific Outcomes. PVEST has been applied to study the development of racial identity and the role it plays in predicting youth academic and socioemotional outcomes, as outlined in the following three example studies. Morton and Parsons (2018) studied the influence of Black women's perceptions of race and gender on their identity development and STEM engagement. This study focused exclusively on the PVEST stage of Net Vulnerability. They found that despite Black women's acknowledgment of the negative attributes ascribed to their racial identity, the Black women interviewed found pride in their racial identity through positive exchanges, interactions, especially with their mothers as role models. The participants' prior experience led them to view their Black woman identity as signifying resilience and persistence, which can reduce their Net Vulnerability during their academic career as a STEM major. Beyond Morton and Parsons' work on Black women in STEM, additional studies outside of the STEM educational context illustrate how all five stages of PVEST can be leveraged to provide a comprehensive understanding of the consequences that risk and protective factors can have for student identity development and positive outcomes.

Leath et al. (2021) apply PVEST to explore how Black women's high school friendship experiences shape their identity development across different racial contexts. Beginning with Net Vulnerability, young women in predominantly White schools faced racial isolation and microaggressions, while those in Black-majority schools had greater access to same-race peer support. Net Stress Engagement involved challenges such as the young women's internal struggle with racial exclusion, Eurocentric beauty standards, and interracial tensions like colorism. In response, participants developed Reactive Coping Strategies, including forming close friendships with other Black girls, code-switching, or distancing themselves from non-affirming peer groups. These experiences shaped their Emergent Identities, where affirming friendships reinforced a positive racial self-concept, while isolation led to feelings of alienation. Ultimately, Life-Stage-Specific Outcomes revealed that high school friendships had lasting effects, with many participants seeking greater racial affirmation and empowerment in college. The study underscores how school racial diversity influences Black girls' identity formation and highlights the importance of supportive peer relationships in mitigating racial stress.

Hope and Spencer's (2017) study on how civic engagement functions as an adaptive coping response for racial minority youth facing systemic inequality. The Net Vulnerability of these students consisted of racial discrimination, political disenfranchisement, and economic inequality, with community support and cultural socialization serving as protective factors. Net Stress Engagement consisted of perceived institutional and interpersonal discrimination. Reactive coping strategies manifested in two ways: adaptive coping through civic engagement (e.g., activism, volunteerism, political participation) and maladaptive coping through disengagement due to systemic barriers. These responses shaped their emergent identities over time. Namely, engaged youth developed identities as activists or community leaders, while disengaged youth adopted political cynicism and marginalization. This identity formation influenced life stage outcomes, where sustained engagement fosters agency, educational attainment, and stronger community ties, while disengagement limited political efficacy and social mobility. These studies are only a few of the many that leveraged PVEST to better understand positive youth development (e.g., McGee and Martin, 2011a,b; Morton and Parsons, 2018; Seaton et al., 2009) however, there is little research that leverages this theoretical lens to design interventions and assess their efficacy, especially in relation to STEM identity development and outcomes. In the following sections, we elaborate on each of the five stages of PVEST as it relates to students' emergent STEM identity and in achieving success in undergraduate math courses.

Net Vulnerability

All STEM students have experienced contexts that present vulnerabilities and protective factors. However, some contexts are unique to minoritized STEM students, and they comprise minoritized students' Net Vulnerability. These contexts should not be viewed as deficits or deficiencies, but instead as a part of their everyday environments (Spencer and Swanson, 2016). Students with certain visible characteristics used to determine race, including skin color, facial features, hair texture, and body type (e.g., Stepanova and Strube, 2009), have had a lifetime of socialization experiences from their family, schools, communities, and greater societal norms based on these characteristics (Dupree et al., 2015). In other words, Net Vulnerability represents students' predisposition to the experience of stress based on their risks and protective factors. These socialization experiences are informed by the greater socio-historical context of minoritized populations, or what Bronfenbrener referred to as the chronosystem and the macrosystem, which have often been exclusionary (McGee, 2016; Riegle-Crumb et al., 2019). Historically people of color, especially African American and Black individuals, have been viewed and treated as secondary citizens and explicitly excluded from educational opportunities (Mutegi, 2013). Even as society now largely disparages overtly racist claims of an inherent deficit of Black and African American individuals in academic performance, these socio-historical beliefs are still commonly seen as implicit biases that play out in students' contexts day to day (Martin, 2009; Mutegi, 2013). For example, recent studies have shown that the academic struggles of Black or Latinx individuals are still often attributed to assumptions about their race/ethnicity's lack of intelligence (Gutiérrez, 2013; Spencer et al., 2016). Yet these racist beliefs are often masked by more socially acceptable group attributions/generalizations such as being low-income, urban life, cultural differences, etc. (Martin et al., 2019; Ngo and Velasquez, 2020; Tyson, 2011). Such implicit biases lead to persistent negative stereotypes (Park et al., 2020; Ridgeway and McGee, 2018). Negative racial/ethnic stereotypes do not exist in a vacuum, they are often coupled with a lack of racial/ethnic representation in the classroom and a lifetime of potentially negative academic experiences (Park et al., 2020; Ridgeway and McGee, 2018).

Scholars of color have long been bringing attention to the structures that have neglected to provide equal opportunities for Black children and other minoritized students (Martin et al., 2019; Ridgeway and McGee, 2018). Bannister et al. (2017) point out how recent reforms such as "mathematics for all" fail to acknowledge the roots of disparities in mathematics environments. Berry et al. (2013) outline how Black youth's math education was neglected in math education reforms taking place from the 1950s to the 2000s. Following legally mandated school desegregation, there were systems put in place that functionally re-established forms of segregation through testing and tracking (Joseph et al., 2017; Larnell, 2016; Martin et al., 2019; Ngo and Velasquez, 2020; Shah, 2017; Tyson, 2011; del Zavala, 2014). Such implicit biases have real impacts on minoritized students' academic achievement and educational experiences. For instance, Copur-Gencturk et al. (2020) found that high school math teachers hold implicit biases about students' mathematical abilities based on their race/ethnicity and gender. Teachers rated Black and Hispanic students as lower in mathematical ability than their White counterparts, even when math performance was comparable. These implicit beliefs are concerning since teachers' expectations and views of their students influence students' academic achievement (McKown and Weinstein, 2008), and teachers are often the gatekeepers for higher tracks that prepare students for undergraduate STEM education.

Another contextual factor that influences teacher and peer implicit biases and minoritized STEM students' Net Vulnerability is the lack of representation of minoritized students in STEM majors, also known as low compositional diversity. Minoritized STEM majors, especially at predominantly White institutions, are more likely to find themselves in an environment where their racial/ethnic group is even less represented than during their K-12 experiences (Riegle-Crumb et al., 2019; Weinberg, 2008). Lee et al. (2020) state that low compositional diversity increases the likelihood of microaggressions, "everyday verbal and nonverbal acts of systemic racism that demean and undermine Black Americans," (Marshall et al., 2021, p. 2), a key component to a negative climate for minoritized students. When institutions have greater compositional diversity, they have higher minoritized student academic success (Dee, 2004; Gershenson et al., 2021; Llamas et al., 2021).

Although the socio-historical context of minoritized STEM students can lead to increased Net Vulnerability, researchers of color have brought attention to the fact that minoritized students also have substantial protective factors they can leverage to successfully navigate academic spaces (McGee and Spencer, 2015). These factors have largely been ignored or assumed to be lacking for these students based on existing stereotypes about minoritized populations. Many assume that minoritized STEM students lack the social support needed for success in STEM education. However, researchers have found that many minoritized students have social supports that assist in the development of positive ethnic-racial identity, positive math self-concept, and academic achievement (Dupree et al., 2015; Hughes et al., 2006). Ethnic-racial socialization is one way in which these social supports provide a protective factor against the vulnerabilities presented by negative stereotypes about minoritized students' academic aptitude (see Bartell, 2011; Brand et al., 2006; Ellington and Frederick, 2010). When minoritized students have experiences that are positive and/or supportive, they can develop protective factors (e.g., positive attitudes towards their STEM ability), which helps them persist in STEM (Smith et al., 2020).

Central to PVEST is that no one group is predisposed to vulnerability, but rather, the interactions between individuals' unique socialization based on their socio-historical, more proximal contexts, and stable personal attributes shape their vulnerability. It is the sum of these factors that makes up each minoritized student's Net Vulnerability in their first-year gateway math course. However, student perceptions of their Net Vulnerability are not uniform, and they are informed by students meaning making of their experiences in various contexts, their Net Stress.

Net Stress

Net Stress consists of the individual's *experience/interpretations* of the risks and protective factors in undergraduate math courses (McGee, 2016). Thus, a student's race or gender may lead them to be predisposed to the experience of an undergraduate math course as stressful. However, not all Black students in undergraduate math courses experience this stress. To use an example from the prior section on Net Vulnerability, Copur-Gencturk et al.'s (2020) findings suggest that Black and Hispanic students are perceived more negatively by their teachers than White students. While being Black makes it more likely that a student will be held to lower academic expectations than being White, Black students' actual experiences of this are what contribute to their Net Stress.

The cultures of STEM gateway courses have real impacts on minoritized students' perceived stressors. Many undergraduate STEM programs' gateway courses are perceived to "weed out" students not considered "strong" enough to persist in scientific endeavors, with calculus courses showing some of the highest D, F, or withdrawal rates (Seymour and Hewitt, 1997; Weston et al., 2019). Such "weed out" courses lead many minoritized students to drop out and thus have a direct impact on diversity in STEM (Mervis, 2011; Seymour and Hewitt, 1997). Many minoritized STEM students state that these gateway courses have a "hostile, competitive classroom culture," (Weston et al., 2019, p. 201). Such negative student experiences may lead many minoritized students to perceive STEM as stressful (McGee, 2016), especially when paired with social identity threats in the form of racist interactions with their STEM faculty (Park et al., 2020). Seymour and Hewitt (1997) found that the most common reasons students (non-minoritized and minoritized) cited for switching from STEM majors are based on negative experiences from the institution (e.g., "turned off by science," poor teaching by STEM faculty, and feeling overwhelmed by the pace and load of curriculum demands). Despite this, minoritized students are more likely to "blame themselves rather than departments, faculty, or institutions, for all, or most of their difficulties," than their non-minoritized peers (Seymour and Hewitt, 1997, p. 324). Such feelings are likely an internalization of our society's deficit thinking of minoritized students, focusing blame on the individual or their respective racial/ethnic community instead of systemic issues in our society (Jong et al., 2020).

In addition, when minoritized students are underrepresented in their STEM major (i.e., low compositional diversity), many have difficulty seeing themselves succeeding in the majors (Morton and Smith-Mutegi, 2018) and experience a lower sense of belonging (Buck et al., 2020; Rainey et al., 2018), in turn increasing their evaluation of such contexts as stressful. In addition, low compositional diversity increases the chances of stereotype threat, which is a fear of confirming negative stereotypes about one's racial/ethnic identity (Aronson, 2002; Lewis and Sekaquaptewa, 2016; Spencer et al., 2016; Steele, 1997; Steele and Aronson, 1995; Thoman et al., 2013). We highlight stereotype threat in the current manuscript because of the extensive body of research about its consequences and interventions relative to the literature on other social identity threats. Minoritized students are keenly aware of the stereotypes and implicit biases about their racial or ethnic groups (i.e., social identity threats, which make up part of their Net Vulnerability; McGee, 2016; Mutegi, 2013; Nasir et al., 2017; Rodriguez and Blaney, 2020). Stereotype threat has been considered a significant barrier to minoritized students' academic achievement (Spencer et al., 2016). Black and African American students in STEM report more concern about stereotyped treatment and less sense of belonging than non-STEM majors (Chavous et al., 2004). Experiencing stereotype threat can negatively influence students' self-evaluations, their intentions to pursue higher STEM education, and their academic success (McGee, 2016; Muenks et al., 2020).

Both being a member of a stereotyped group and being aware of the stereotype are two factors that lead to students being likely to experience stereotype threat, but stereotype threat is only one way in which students interpret these greater social identity threats (Verkuyten et al., 2019). Just because a student is a member of a group that is stereotyped, aware that there is this stereotype, and in a group context predisposed to experiencing stereotype threat (i.e., a Black student in an undergraduate math course with all other students being white) does not mean the student will automatically undergo stereotype threat and that they will experience their math course as stressful (Steele et al., 2002).

Minoritized STEM students better equipped to navigate hostile environments, are less impacted by low compositional diversity, and likely experience less stereotype threat, when they experience identity-affirming contexts outside of their major, e.g., positive ethnic-racial socialization, supportive family, peers, or organizations (Jong et al., 2020; McGee and Martin, 2011a; McGee and Martin, 2011b). Some people think that awareness of historical oppression may lead to students feeling defeated in STEM contexts; however, having greater ethnic-racial socialization supports minoritized students' academic success (Dupree et al., 2015; Hughes et al., 2006). In fact, minoritized students' perceived ethnic-racial socialization is associated with the development of positive ethnic-racial identities and academic achievement (Hughes et al., 2006). Even though minoritized students with positive ethnic-racial identity still face many deficit focused academic stereotypes,

> "(a) They also have a critical understanding of the structural or systemic forces that work against the positive development and achievement of racial and ethnic minorities, and (b) they seek to actively resist these forces. Specifically, they resist assumptions that they are underachievers and assumptions about the superiority of members of the majority culture." (Dupree et al., 2015, p. 126).

Hence, minoritized STEM students who have learned to navigate such contexts previously might not find these experiences as stressful. Having a faculty member invested in a minoritized student's success, and who emphasizes collaboration and teamwork, can help mitigate the stress caused by such hostile academic environments (Foltz et al., 2014; Hernandez et al., 2017; Moore et al., 2020). Having access to identity-affirming spaces, either with peers, instructors, or mentors, could help the student shift the blame from themselves, likely reducing their Net Vulnerability and Net Stress (King and Pringle, 2018).

Reactive coping strategies, emergent identities, and stage specific outcomes

Although Net Vulnerability (the sum of all the supports and vulnerabilities in the context) and Net Stress (the sum of the students' meaning making/interpretation/perception of those supports and vulnerabilities) play a significant role in their STEM experiences of minoritized students, they do not determine their success in STEM; students' Reactive Coping Strategies, Emerging Identities, and Stage Specific Coping Strategies also need to be considered. Reactive Coping Strategies are the initial responses the student has to their Net Stress. Stereotype threat, as discussed in the previous section, activates a negative stress response (e.g., worry), leading to anxious thoughts (Johns et al., 2008). A common Reactive Coping Strategy to stereotype threat is attempting to suppress the anxiety and worry (Aronson, 2002; Johns et al., 2008; Schmader and Johns, 2003). However, this imposes a cognitive burden on the individual and limits the cognitive resources available, leading to lower academic performance. This may influence the students' Emergent Identity formation by making them feel that they are not a math individual and choose not to pursue further STEM education (the Stage Specific Coping Outcome). Research on STEM identity in minoritized populations clearly shows that students' self-efficacy beliefs are one key component of the development of a STEM identity, which influences their persistence in STEM (Carlone and Johnson, 2007; Dou and Cian, 2022; Godwin et al., 2016; Hazari et al., 2010).

Protective factors not only reduce Net Vulnerability and Stress, but can also promote adaptive Reactive Coping Responses and contribute to positive Emergent Identity formation. Positive emergent identities develop when minoritized students think of their group membership in ways that highlight group strengths, which then leads to persisting in STEM (the Stage Specific Outcome). Spencer and Swanson (2016) suggest that cultural traditions (or religious identity; Brittian and Spencer, 2012) or "referent others" (or culturally affirming mentors or community members; McGee and Spencer, 2013) are influential in how students react to stress. For example, students who have a more salient religious identity may turn towards prayer, as their Reactive Coping, to reduce their autonomic arousal when faced with stress. This then allows for more cognitive resources to be available during academic tasks, increasing achievement, self-efficacy, promoting the development of math/science identities as Emergent Identities, and increasing the likelihood of STEM persistence, the Stage Specific Outcome. Several works specifically demonstrate how supportive experiences lead to the development of math/STEM identities and persistence in STEM for minoritized students (Godwin et al., 2016; Morton and Parsons, 2018; Singer et al., 2020).

Intersectionality

No one is solely defined by their race/ethnicity, gender, or any other identity they may subscribe to. This is due to intersectionality (Crenshaw, 1989), that every individual exists within interlocking systems of oppression, and everyone lies at different intersections of these various systems.

> "The term intersectionality references the critical insight that race, class, gender, sexuality, ethnicity, nation, ability, and age operate not as unitary, mutually exclusive entities, but as reciprocally constructing phenomena that in turn shape complex social inequalities," (Collins, 2015, p. 2).

According to PVEST, the nature of intersectionality leads to everyone experiencing different supports and vulnerabilities which they then must interpret through the lens of their unique experience (Velez and Spencer, 2018).

Despite it being critical to consider intersectionality to interpret the diverse experiences and outcomes of minoritized STEM students, previous research on minoritized STEM students has not given much consideration to the impact of intersectional identities (Grabe, 2020; Cochran et al., 2020). Currently, there are differing perspectives on how multiple intersectional minoritized identities impact individuals' experiences of vulnerability (Purdie-Vaughns and Eibach, 2008). Some researchers argue that the more minoritized identities one subscribes to (e.g., being Black and a woman) the more vulnerability and stress one will experience, whereas others argue that when an individual subscribes to multiple minoritized identities they can become invisible due to then being a less prototypical example of their various identities, leading to various advantages and disadvantages.

The intersectionality between race and gender has received the most attention in STEM education. The data clearly shows that women of color have the lowest STEM degree attainment and have the lowest representation in STEM compared to their representation in higher education and the general population (Malcom et al., 1976; Ong et al., 2011). Rainey et al. (2018) found that women of color reported the lowest sense of belonging in STEM fields compared to white men, white women, and men of color, particularly in the physical sciences where they are the least represented. These findings are supported by many rich qualitative studies which suggest that although women of color are just as likely to have intentions/interests in pursuing STEM negative experiences with the competitive culture of STEM that is often at odds with some of their identities (Carlone and Johnson, 2007; Ong et al., 2011; Morton and Parsons, 2018). Ong et al. (2018) show that having access to opportunities for recognition and relationship building in STEM is critical to women of color's positive experiences in STEM, particularly in counterspaces. Counterspaces are, "academic and social safe spaces that allow underrepresented students to: promote their own learning wherein their experiences are validated and viewed as critical knowledge; vent frustrations by sharing stories of isolation, microaggressions, and/or overt discrimination; and challenge deficit notions of people of color (and other marginalized groups) and establish and maintain a positive collegiate racial climate for themselves," (Ong et al., 2018, p. 209). This work with a focus on the intersection between race and gender is critical especially since "history has borne out the reality that programs intended to serve women disproportionately benefit White women, and programs intended to serve minorities mainly benefit minority males," (Ong et al., 2011, p. 176).

According to PVEST, the impact of intersectional identities on STEM success will be unique depending on the different identities and the individual (Velez and Spencer, 2018). Currently, the literature exploring intersectionality with social class, disability, and sexuality is limited (Cochran et al., 2020). This makes it more critical that STEM support programs and interventions be created based on a flexible framework, such as PVEST, to help support the many intersecting identities of STEM students.

PVEST and current interventions for STEM success

PVEST contributes several key perspectives that are currently missing from the current interventions intended to support minoritized STEM students. PVEST highlights that students are not defined by their "risk factors." Instead it uses an asset-based approach by requiring the consideration of: 1. the entire sociocultural context of the student (including their supportive contexts), 2. the individual differences between students in their meaning making/perception/interpretation of their context (e.g., the role of their intersectional identities), and 3. both the proximal (e.g., using adaptive coping responses) and distal (e.g., holding a math/STEM identity) outcomes and their role in the future experiences of the student. Given that PVEST outlines a cyclical and reciprocal series of events that develop students' identity, it is important to note that all five stages of the PVEST both affect and can be affected by interventions. Theoretically, the more stages of PVEST an intervention considers and effectively attunes to, the more likely an intervention is to succeed (Spencer et al., 2012). However, we currently do not know of any interventions for minoritized STEM students that take PVEST into consideration.

Several existing interventions show promise in reducing minoritized STEM students' Net Vulnerability and/or Net Stress while helping them have more adaptive Reactive Coping, build a STEM identity, and succeed in STEM gateway courses. These interventions target key factors associated with math performance, specifically stereotype threat, math anxiety, motivation, and collaborative learning. However, each of these interventions addresses different PVEST stages in different ways, and since each of these interventions are often implemented independently it is not clear how these different supports interact to influence students' outcomes. In addition, these interventions often do not properly consider the entire sociocultural context of the student and assume that all minoritized STEM students need the same type of support. Future work is needed to make the current math achievement interventions more aligned with the PVEST framework.

Despite these limitations, these interventions on stereotype threat, math anxiety, motivation, and collaborative learning are worth considering for application with minoritized STEM students since they have been demonstrated to improve math or academic achievement under some circumstances. Stereotype threat, as discussed earlier, is a stress response arising when minoritized students fear confirming a negative stereotype about one of their identities (Spencer et al., 2016; Steele and Aronson, 1995). Interventions for stereotype threat are varied and address minoritized students' beliefs or resilience (Liu et al., 2021). Math anxiety, defined as the tension and apprehension elicited by math contexts, is similar to stereotype threat in that it too impacts available cognitive resources by increasing worry (Ashcraft and Kirk, 2001; Johns et al., 2008). Most current math anxiety interventions involve helping students to engage in relaxation techniques (Chang and Beilock, 2016). Motivation is made up of a wide range of constructs generally relating to the beliefs, values, and goals that guide students' actions and persistence (Wentzel et al., 2009). Most motivation interventions target students' confidence in a domain or task, their attributions of their academic performance or social belonging, or their values (Lazowski and Hulleman, 2015). Each of these types of interventions addresses how students experience, interpret, or react to their experience in their gateway math courses (i.e., their Net Stress and Reactive Coping in PVEST terms).

Although stereotype threat, math anxiety, and motivation interventions intervene on varied factors associated with Net Stress or Reactive Coping, all these interventions focus on influencing the students' perception or reactions, rather than on systemic factors such as lack of compositional diversity. Collaborative learning interventions on the other hand specifically focus on creating environments that provide social and academic support specifically for minoritized STEM students, directly addressing Net Vulnerability. The following sections provide an overview of the literature on the four intervention domains and how minoritized STEM students can benefit from them, especially as they relate to the PVEST framework. Given the focus on academic interventions that largely target students' Net Vulnerability, Net Stress, or Reactive Coping, discussion of Emerging Identities and Stage Specific Outcomes will be more limited.

Mitigating stereotype threat

According to Liu et al. (2021), most stereotype threat interventions applied to minoritized students can be categorized into two categories: belief-based and resilience-based. Belief-based interventions aim to blur group boundaries, promote sense of belonging, and/or provide successful in-group role models. Resilience-based interventions encourage reappraisal/reattribution, aim to increase confidence in a specific domain, and/or focus on values-affirmation.

Many stereotype threat interventions are based on motivation interventions, such as those that aim to influence student's attributions of their intelligence (Aronson et al., 2002), increase students' sense of belonging (Walton and Cohen, 2007), and affirm students' values (Cohen et al., 2006, discussed in more detail in the motivation section below). Besides motivation-based interventions, other interventions aim to reduce stereotype threat by asking students to reflect on threats to their ethnic-racial identity. Ben-Zeev et al. (2017) evaluated the effects of a stereotype threat reflection intervention on students' performance in an abstract reasoning task. 40 Black/African American and 210 Latinx STEM students were presented with either a stereotype threat reflection intervention, values affirmation intervention, or no intervention. The stereotype threat reflection consisted of a brief module on stereotype threat followed by reasoning about a hypothetical situation in which they or a friend was experiencing stereotype threat and writing about what they would tell themselves or their friend to help cope. Minoritized students in the stereotype threat reflection intervention reported decreased concerns about stereotype threat and higher abstract reasoning scores compared to the control group.

Most other studies of stereotype threat interventions have focused on age groups and/or content different from undergraduate STEM but may still be relevant. Bikmen (2015) explored the effects of a historical narrative intervention (about the Little Rock Nine, highlighting the resilience of the first 9 Black students to enter Little Rock Central High School during desegregation versus a control narrative about the Berlin Wall) on 51 Black undergraduate students' performance on a verbal task. Students with high identification with their racial group did worse with the control narrative than the resilience narrative, suggesting that messages of resilience could serve as a protective factor. In another intervention study, Alter et al. (2010) found that framing an activity as an opportunity for learning, instead of as a test of ability, reduced the impact of stereotype threat on Black children's test performance. Similarly, Johns et al. (2008), found that a reframing intervention improved working memory performance for Latinx undergraduate students.

Despite some stereotype threat specific interventions being conducted on minoritized populations, most have not specifically addressed undergraduate mathematics or STEM. Most stereotype threat specific interventions for mathematics have been applied to women (Liu et al., 2021; Nguyen and Ryan, 2008). For women, effective interventions include teaching them about stereotype threat (Johns et al., 2005; but see Merillat et al., 2018 for a not significant result with high schoolers), completing an interest and personality questionnaire (Ambady et al., 2004), thinking about similarities between males and females (Rosenthal and Crisp, 2006), and replacing stereotype threat related thoughts with thoughts about an important personal identity (Logel et al., 2009). However, recent meta-analyses call into question the effect of stereotype threat on women, with Picho-Kiroga et al. (2021) finding that stereotype threat effects for women have been inflated, while Warne (2022) argues that the stereotype threat effect for women is negligible. However, it is important to note that the vast majority of this work has not considered how stereotype threat in general and stereotype threat interventions more specifically function under the context of intersectional identities, e.g., for women of color.

Using the PVEST framework, stereotype threat interventions can be understood through their effects on Net Stress and their objective to help students have more adaptive Reactive Coping. Stereotype threat interventions are intended to reduce Net Vulnerability and Net Stress by buffering the experience of social identity threats and sometimes explicitly training students in more adaptive Coping Responses. For example, in the Ben-Zeev et al. (2017) intervention, students' meaning making of stereotype threat is directly addressed by having students explicitly think about how stereotype threat could impact them and to brainstorm ways to reframe the threat(s) to limit its negative effects. Although stereotype threat interventions acknowledge the sociocultural context of the student and can help students focus on the supports and protective factors in their environment, they currently do not account for the individual differences in students' experiences, particularly those associated with their intersectional identities, which is one of the key contributions of PVEST. Approaching such interventions with a PVEST perspective can help us anticipate which students benefit from stereotype threat interventions and in which contexts, rather than expecting such interventions to benefit all minoritized STEM students across all settings. One of the key conditions for stereotype threat is that an individual must identify with the domain in which they are performing a task (Aronson, 2002; Spencer et al., 2016). In their meta-analysis, Nguyen and Ryan (2008) showed that several moderators (stereotype threat relevance, domain identification, and task difficulty) influence the effects of stereotype threat on minoritized students. For instance, they found that stereotype threat effects were larger in contexts where the threat was explicit. Thus, stereotype threat interventions are only expected to apply to minoritized students who have already developed a STEM identity.

In addition, stereotype threat is not the only source of stress that minoritized STEM students experience. Sackett et al. (2004) state that although stereotype threat might play some role in the difference in achievement between White and minoritized students, it is not necessarily the primary or sole contributor to minoritized student underrepresentation, and that other factors should not be ignored. Factors other than social identity threats, such as math anxiety and low math self-efficacy, can also influence students' phenomenology with a negative impact on mathematics performance and can interact with processes such as stereotype threat. Utilizing a PVEST perspective helps us consider the role of other factors of Net Stress, how they may interact with stereotype threat, and how interventions can address these different sources of stress.

Reducing math anxiety's impact on student success

Mathematics anxiety is "a feeling of tension, apprehension, or fear that interferes with math performance" (Ashcraft, 2002, p. 181). Math anxiety is a significant threat to achievement and persistence in STEM due to the high emphasis in many STEM courses on quantitative skills (Chang and Beilock, 2016; Hembree, 1990; Maloney and Beilock, 2012; OECD, 2013; Ramirez et al., 2018; Stankov and Lee, 2017). Math anxiety reduces math achievement, leads students to opt out of higher mathematics in high school, and makes students less likely to pursue STEM fields in higher education, especially as the material gets more difficult and the stakes get higher (Ahmed, 2018; Hembree, 1990). Some studies find higher rates of math anxiety in minoritized students (Ahmed, 2018; Cheema and Sheridan, 2015; Gabriel et al., 2019; Hembree, 1990; Onwuegbuzie, 1999; Young and Young, 2015), but even moderate amounts of math anxiety could have negative impacts on minoritized students' STEM success and persistence. Math anxiety is a vicious cycle. Math anxiety leads to math avoidance, math avoidance leads to decreased math performance, and decreased math performance further exacerbates math anxiety. In addition, math anxiety undermines students' motivation to continue to engage in math (Hembree, 1990; Luttenberger et al., 2018). Thus, minoritized students who want to pursue less computationally heavy STEM fields, such as biology, might move away from their major due to experiences in their math gateway courses.

Historically, the etiology of the relationship between math anxiety and poor math performance has been debated. Some believe that poor math performance and achievement are a product of math anxiety, while others believe that math anxiety is a product of poor math skill (Ramirez et al., 2018). Research supporting the view that math anxiety leads to poor math performance centers on the role of working memory. Working memory is a cognitive workspace in which on-line information is temporarily stored and manipulated (Miyake and Shah, 1999), and it is essential for complex cognitive tasks such as mathematics (Raghubar et al., 2010). Heightened math anxiety is known to increase worry, worry then uses up some of the available working memory resources and limits the amount available for the task at hand (Ashcraft and Kirk, 2001). Ashcraft and Kirk (2001) found that when individuals were required to complete math problems while holding random letter sets in working memory, individuals with high math anxiety made more errors in reciting the letters held in working memory than individuals with low math anxiety. These findings suggest that the math performance impairments associated with math anxiety are an outcome of the additional cognitive burden on working memory.

In contrast, some research supports the idea that math anxiety is a product of poor math skill. Ma and Xu (2004) conducted a longitudinal study of seventh to twelfth grade students, measuring math anxiety and math achievement annually for 5 years. They found that low math achievement at earlier time points predicted higher math anxiety at later time points, and that these effects were significantly larger than those assessing math anxiety at earlier time points predicting math achievement at later time points. Gunderson et al. (2018) also found comparable results, supporting the idea that math anxiety is a product of poor math skill. However, these findings cannot account for how poor math skill leads to math anxiety (Ramirez et al., 2018).

More recently, Ramirez et al. (2018) proposed that "students' development of math anxiety is largely determined by how they interpret (i.e., appraise) previous math experiences and outcomes (rather than the outcomes themselves)," (p. 151). This view is well aligned with PVEST's conceptualization of how students' meaning making of their Net Vulnerabilities shapes their Net Stress. According to PVEST, math anxiety could be more detrimental to minoritized STEM students than it is to their non-minoritized peers. Math anxiety, like stereotype threat, is a factor that is related to the individual's previous math experiences and identity (Net Vulnerabilities) and their perceptions thereof (Net Stress). A student's tendency to experience math anxiety in math contexts is part of their Net Vulnerability, however, their experience of math anxiety in real time is part of their Net Stress due to the role of their meaning making of the real-time physiological and psychological experience of math anxiety. The parts of their Net Vulnerability and Net Stress caused by the math anxiety can then interact with other sources of vulnerability, support, or stress to influence their math performance. For example, minoritized STEM students with math anxiety who have had previously supportive math contexts could have lower Net Vulnerability compared to those with math anxiety who have not had supportive math contexts. Having a supportive math context is likely to encourage more positive perceptions of math, thus lowering Net Stress, which could then mitigate the negative effects of math anxiety on math performance. However, many minoritized STEM students have experienced negative math environments due to racialized experiences in the classroom, low compositional diversity, etc. (Park et al., 2020; Ridgeway and McGee, 2018). Such negative contexts make it more likely that students will have negative perceptions of math, which increases their Net Stress and increases the chances of math anxiety having a negative impact on math performance. In each of the scenarios described, stereotype threat could also interact with the individual's math anxiety, potentially compounding the Net Stress experienced and increasing the likelihood of maladaptive reactive coping responses.

Two categories of interventions show promise for mitigating the negative impacts of math anxiety, and potentially stereotype threat, by targeting reactive coping responses: relaxation training (Brunyé et al., 2013; Sharp et al., 2000) and expressive writing (Park et al., 2014; Ramirez and Beilock, 2011). Relaxation exercises, such as guided breathing and meditation, have positive emotional benefits in a wide variety of groups (Chambers et al., 2009), and there is some evidence to suggest that they reduce the negative experience of math anxiety and improve math performance. Sharp et al. (2000) found that students who were given 5–7 min of relaxation training for 6 class sessions of a mathematics class reported lower math anxiety and had higher scores on math skill measures than students in a "business as usual" class. Similarly, Brunyé et al. (2013) found positive effects of a guided mindfulness exercise (focused breathing) for university students with high math anxiety on math task performance; individuals with low math anxiety were not affected by the breathing condition. Relaxation exercises have also been shown to be effective for stereotype threat (Weger et al., 2012), perhaps because it leads to worry and impaired working memory function (Schmader and Johns, 2003), much in the same way math anxiety does.

Expressive writing has also been shown to benefit students in high-pressure academic settings (Ramirez and Beilock, 2011). Ramirez and Beilock (2011) found that students in a 10-min expressive writing intervention (write about their anxiety) performed better on a modular arithmetic task compared to the control group (write about their day). Park et al. (2014) found that expressive writing improved math performance on a modular arithmetic task for individuals with high math anxiety compared to a control group, but there was no benefit for non-math anxious students.

Both expressive writing and relaxation training provide strategies to manage the negative thoughts associated with math anxiety, theoretically freeing up the cognitive resources for mathematics that may have been consumed by anxious thoughts (Sweller et al., 1998). Reduction of anxiety may also lead to less aversion to mathematics and thus greater engagement with math tasks (Beilock and Maloney, 2015). From the lens of PVEST, interventions such as relaxation training (Brunyé et al., 2013; Sharp et al., 2000) and expressive writing (Park et al., 2014; Ramirez and Beilock, 2011) can be particularly helpful in reducing Net Stress and addressing the maladaptive Reactive Coping responses that are a product of math anxiety, and potentially social identity threats more generally.

Most studies of math anxiety interventions have two methodological strengths: random assignment and utilization of active control groups. Nonetheless, they have several limitations: (1) most notably they do not report racial/ethnic demographics of their sample, making it impossible to conclude how such interventions specifically function across race/ethnicity; (2) they only assess short-term benefits, so it is unclear whether the effects of the interventions are lasting or effective when repeated; and (3) there are very few studies conducted which specifically assess the efficacy of these techniques specifically for individuals struggling with math anxiety. These limitations can be addressed by utilizing a PVEST framework. Considering that minoritized STEM students do not all struggle with the same obstacles, it is important to provide them with interventions that address the different processes that lead to STEM success. Other potential interventions targeting Net Stress are based on the motivation literature.

Motivation and minoritized students' math achievement

Like stereotype threat and math anxiety, students entering gateway STEM courses also face threats to their motivation. Motivation is a multi-dimensional construct described by Wentzel et al. (2009, p. 1) as "the energy [students] bring to [academic tasks], the beliefs, values, and goals that determine which tasks they pursue and their persistence in achieving them and the standards they set to determine when a task has been accomplished." Several frameworks for academic motivation have been used to understand student STEM beliefs and behaviors. For example, prior research has focused on students' goals in STEM courses (i.e., student's main objective is to avoid demonstrating failure, demonstrate success, and/or learn the material; Brodish and Devine, 2009; Smith, 2006; Thoman et al., 2013), students' sense of belonging in STEM courses (Thoman et al., 2013), and students' decreased domain identification, or how much success in a course is related to their identity (Thoman et al., 2013). Motivation is a crucial factor in minoritized students' achievement and persistence in STEM fields (Hall and Ponton, 2005; He, 2014; Simon et al., 2015; Stevens et al., 2004; Waller, 2006; Wood et al., 2015). Struggles with motivation in STEM areas are associated with decreased STEM persistence and achievement (Rosenzweig and Wigfield, 2016).

Due to the multidimensional nature of motivation, many different interventions have been developed to address the varied aspects of motivation to increase STEM success. For this review, motivation interventions will be grouped into the following three categories: self-efficacy, attribution, and values interventions.

Efficacy of self-efficacy interventions

An individual's evaluation of his or her abilities (self-efficacy) has important consequences for performance and persistence (Bandura, 1977). A student who has low confidence is likely to get frustrated and give up when faced with challenges during learning. Self-efficacy is positively related to STEM academic outcomes (Parker et al., 2014), and it plays a significant role in minoritized students' achievement and persistence in STEM (Stewart, 2006).

Luzzo et al. (1999) compared the impact of a direct success experience (completing easy number series tasks that they were told assessed mathematical abilities), to a vicarious success experience (watching a video of a former student share their math and science success experiences), and a control condition. At a four-week follow-up, individuals in the direct success intervention had higher self-efficacy, were more likely to report choosing STEM majors, and enrolled in more math and science courses in the following semesters compared to individuals in the other two groups. Jansen et al. (2013) also found positive effects of direct success experiences on children's math anxiety, perceived competence, and math performance in elementary-grade students. Vicarious success experiences also have promise, although not in Luzzo et al. (1999). Ashby Plant et al. (2009) randomly assigned students to interact with a male virtual agent, a female virtual agent, or no agent. The virtual models presented information about successful female engineers, the benefits of an engineering career, and presented information to counteract the stereotype that engineering is cold and unwelcoming to women. Both boys and girls assigned to the female agent had greater engineering self-efficacy, improved performance on a math measure, and displayed higher STEM interest than those in the control groups. In related work, presenting African American students with successful models boosted their performance on a GRE-like exam (Shapiro et al., 2013). These findings suggest that seeing diverse models have success in STEM could be important for minoritized students' STEM self-efficacy.

In the context of PVEST, these interventions may be thought of as reducing Net Stress by making experiences of success more salient. However, there are very few studies in this vein that focus on STEM achievement and even fewer that are specific to minoritized STEM students. The studies that do exist do not address most of the key contributions of PVEST. These types of interventions, although promising, need to be explored with a more holistic approach to assess whether they are key to minoritized students' STEM success.

Efficacy of attribution interventions

Attribution interventions are related to more general self-efficacy interventions but specifically focus on the individual's interpretation of success and failure experiences, including four main attributions: ability, effort, task difficulty, and luck (Weiner, 1986). There are two types of attribution interventions: those aimed at getting students to attribute success/failure to effort rather than ability, and those aimed at increasing students' sense of belonging by framing struggle as a normative experience.

Effort attribution interventions

Interventions attempting to change students' attributions either change the type of feedback students receive or directly instruct students about the malleability of intelligence. Mueller and Dweck (1997) found that fifth graders praised for effort exhibited better task performance, greater task persistence, and more task enjoyment than students praised for intelligence on a cognitive task. Schunk and Cox (1986) assessed the effects of effort feedback ("you have been working hard") in children with learning disabilities and found that effort feedback was associated with higher self-efficacy and higher performance on the math task. Okolo (1992) similarly found positive effects of effort feedback on children's performance in a math game. Taken together, these studies suggest that helping students to reattribute their success and failures to effort, or lack thereof, has the potential to improve math performance. Recent evidence also supports the efficacy of attribution interventions that directly target student intelligence beliefs.

In a seminal study, Blackwell et al. (2007) evaluated the effects of an 8-session intelligence-based attribution intervention on low-achieving, low-SES middle school students (primarily African American and Latino). While students in the control conditions exhibited a decrease in their math achievement from fall to spring of 7th grade, participants in the intervention group did not show a decline in their math achievement. Paunesku et al. (2015) tested the efficacy of a shorter, computer-based intelligence mindset intervention on a large sample of diverse high school students and found positive effects on grades in core academic subjects (i.e., math, English, science, and social science). Similarly, Yeager et al. (2016a,b) found positive impacts of a computerized mindset intervention in a large-scale study of high school students in ten schools around the country. More recently, Yeager et al. (2019) demonstrated similar benefits with a brief one-hour version of the interventions on a large national sample of high school students on math and science grades and enrollment in advanced math courses.

Interventions that attempt to alter the attributions individuals make about their performance have also shown promise in mitigating the negative effects of stereotype threat. Good et al. (2003) assessed the effect of an intelligence attribution intervention on the performance of female, minority, and low-income middle school computer science students. Students were randomly assigned a mentor and to one of four conditions: incremental beliefs of intelligence message, unstable and external attribution of academic achievement message, combined (included both incremental and attribution) messages, or a control condition. Good et al. (2003) found that students in any of the three experimental conditions outperformed their counterparts in the control condition. Aronson et al. (2002) also found positive effects of an intervention in which African American

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undergraduates wrote letters to pen pals focusing on the malleability of intelligence; these students had higher GPAs and endorsed greater enjoyment of education than those in the control conditions. Similarly, Broda et al. (2018) found benefits of such a mindset intervention for Latinx undergraduate students on GPA.

Despite being tested in large, randomized control studies, a recent meta-analysis by Sisk et al. (2018) exploring the effects of mindset on academic achievement generally found only a small correlation $r = 0.1$ between holding an incremental mindset and academic achievement and no overall benefits of mindset interventions. They noted that mindset interventions might be specifically useful to minoritized individuals, but they did not analyze their findings by race/ethnicity. Comparable results were found by Burnette et al. (2022), even when looking at interventions that targeted specific groups. Macnamara and Burgoyne (2023) found an even smaller effect size with the conclusion that mindset interventions overall did not have a significant impact on academic achievement. These findings suggest that the benefits of mindset interventions to academic achievement are minimal at best. Given the current state of the literature, it is not clear that mindset attribution interventions would be beneficial for promoting minoritized students' success in STEM fields.

Sense of belonging interventions

Belongingness interventions can be similar in vein as attributional interventions (McPartlan et al., 2020). For example, in Wilson and Linville's (1982, 1895) attribution intervention, participants were presented with materials that highlight academic struggle as normative. Sense of belongingness interventions use a similar procedure as used in Wilson and Linville (1982, 1895). However, instead of addressing students' attributions of their academic ability, belongingness interventions focus on attributions of academic success within the context of normative academic struggle. Walton and Cohen (2007) randomly assigned Black 1st-year undergraduate students to one of two conditions. In the intervention condition, students were presented with information from a senior survey that included quotes encouraging them to think of adversity as a common and transient aspect of university adjustment, and not as a fixed struggle. In the control condition, students were provided with information from a senior survey containing generic information about how students' social–political views became more sophisticated over time. Walton and Cohen's (2007) findings suggest that such interventions are likely to improve minoritized students' sense of belonging and university performance. Those in the belongingness intervention condition spent more time studying, communicated with professors more frequently, expressed more confidence in their academic abilities, and increased their GPA over time. Similarly, Walton and Cohen (2011) found that African American university students receiving the sense of belonging intervention had higher academic achievement compared to students who received no such instruction. Yeager et al. (2016a,b) found similar positive impacts on university academic outcomes in large samples of high school and university students. In a recent follow-up of the students assessed in Walton and Cohen (2007, 2011), 7 to 11 years later, Brady et al. (2020) found that those who participated in the intervention had higher career satisfaction and success compared to those in the control condition. These findings were mediated by university mentorship; those who participated in the intervention were more likely to report having a mentor in university, and having a mentor predicted their career satisfaction and success.

PVEST and attribution interventions

In the context of PVEST, attribution interventions specifically focus on altering students' meaning making of their attributions of academic performance or social belonging, addressing Net Stress. STEM environments could pose unique pressure on minoritized students' Net Stress compared to the general university environment. For example, STEM majors tend to be less diverse, in both the student and faculty population, than other majors (Riegle-Crumb et al., 2019; Weinberg, 2008). This could make a lack of social belonging more salient. However, the efficacy of mindset and sense of belonging attribution interventions is still widely debated (Burnette et al., 2022; Macnamara and Burgoyne, 2023; McPartlan et al., 2020; Sisk et al., 2018). More work, specifically exploring the benefits of sense of belonging interventions for minoritized STEM students is needed.

Some studies have not found significant benefits of such sense of belonging interventions (Broda et al., 2018; Hausmann et al., 2009). McPartlan et al. (2020) suggest that null effects of sense of belonging interventions could be due to heterogeneity in the samples and the program contexts. However, even successful sense of belonging interventions are color-blind in nature, many of the sense of belonging interventions described here do not specifically address the unique obstacles and experiences of minoritized students, often explicitly telling participants that regardless of demographics, all students experience difficulties adjusting to university life (Walton and Cohen, 2007, 2011). Although such a statement is true to an extent, it ignores the structural inequities and the day-to-day realities of minoritized students in higher education. Such color-blind messaging could come off as gaslighting minoritized students' lived experiences, who are keenly aware of the difficulties unique to their race/ethnicity in STEM. Ben-Zeev et al. (2017) found that color blind messaging produced similar stereotype threat effects as traditional manipulations of threat. Some may argue that highlighting that struggle in the transition to university is normative across all demographics, without explicitly denying the specific struggles of minoritized students, is not necessarily ignoring structural inequities. However, when the lived experiences of minoritized STEM students are not specifically acknowledged, how can a true sense of belonging be cultivated?

These key limitations of attribution interventions could be addressed by utilizing a PVEST framework. These interventions are often applied without consideration of the sociocultural context of the student or accounting for the individual differences in experiences based on their intersectional identities. In addition, the current conceptualization does not account for other sources of Net Stress which we have discussed, such as stereotype threat and math anxiety. This highlights that a holistic framework is necessary to address the limitations of the current approaches.

Efficacy of values interventions

In addition to self-efficacy and attributions, another factor that influences students' motivation is the extent to which a task or goal aligns with one's values (Eccles, 1983; Eccles and Wigfield, 2002). Current values-based interventions focus on either increasing individuals' views of task value, specifically utility value (how the task relates to one's future goals), or reaffirming individuals' personal values (what they value in their life in general, e.g., family, education, and community). Both types of values have been demonstrated as being important for student persistence (Lazowski and Hulleman, 2015). It is known that experienced and perceived cultural mismatch between minoritized students' personal values and those of their institution/department is a predictor of leaving STEM fields of study (Beasley and Fischer, 2012; Seymour and Hewitt, 1997).

Acee and Weinstein (2010) evaluated the effect of a comprehensive task values intervention on students enrolled in an undergraduate statistics course. Participants in the intervention group completed a series of activities intended to bring their attention to the possible value of statistics; participants in the control group were given passages on multicultural learning. Acee and Weinstein (2010) found increases in task value and positive effects of the intervention on student exam performance with one instructor. Canning and Harackiewicz (2015) found that undergraduate students' performance on a mental arithmetic task benefited from a similar intervention targeting students' task values. Other studies have supported the efficacy of such task-value interventions for minoritized students in biology (Canning et al., 2018; Harackiewicz et al., 2016; Hecht et al., 2019).

In contrast to task value interventions, in which the objective is to get students to think of the specific value of the task in question, values affirmation interventions focus on getting students to affirm their general, core personal values. Although values affirmation exercises are not directly tied to a certain domain, they are thought to benefit the individual by reaffirming one's identity, making it less vulnerable to outside threats by reminding students of their greater life values (Brady et al., 2016; Harackiewicz et al., 2014). Brady et al. (2016) assessed the long-term effects of a values affirmation exercise (ranking importance of different values such as religion or humor and writing about their most important value) in Latino and White undergraduate students. Latino students positively benefited from the affirmation intervention, receiving higher GPAs and feeling more positive about their academic performance than students who did not receive the affirmation intervention. Similarly, African American middle school students participating in a values affirmation exercise received higher grades than those who completed an exercise based on their least important values; the increased achievement was maintained over a two-year follow-up (Cohen et al., 2006; Cohen et al., 2009). Values affirmation interventions have also shown benefits for academic achievement in other samples, such as Latino middle school students (Sherman et al., 2013), first-generation students in an introductory biology course (Harackiewicz et al., 2014), and African American students on standardized GRE-like tests (Shapiro et al., 2013). Women's performance in physics (Miyake et al., 2010) and engineering (Walton et al., 2015) courses or math tasks (Martens et al., 2006; Shapiro et al., 2013) have also been found to improve following values affirmation exercises. However, Bancroft et al. (2017) did not find significant effects of their values affirmation intervention on standardized math performance in a sample of ninth-grade African American and Latinx students, making it unclear whether such an intervention is beneficial specifically for minoritized students' math achievement.

PVEST and values interventions

In the context of PVEST, values interventions provide an additional opportunity to address students' meaning making to reduce Net Stress. These interventions specifically direct students to reflect on how the task at hand is beneficial to their goals or to remember their core values, ostensibly to buffer them against threats to their social identities. The results of studies evaluating values interventions should be treated with caution; most published values interventions have not been conducted with minoritized university students in math contexts. Currently, there is some disagreement on the overall benefit of values affirmation exercises in general. Scaled-up versions of values affirmation interventions show more variability in implementation fidelity, with teachers not strictly complying with the protocol (Bradley et al., 2016; Hanselman et al., 2017). Such failures in implementation fidelity and variability in contexts could account for the inconsistent effects of the task value intervention in Acee and Weinstein (2010) and three large studies' failure to replicate previous values affirmation effects (Dee, 2015; Hanselman et al., 2017; Protzko and Aronson, 2016). Some of these failures could be accounted for by considering the contributions of PVEST, mainly the need to consider the sociocultural contexts of the students and the individual differences that exist among them in the implementation of the interventions. Some suggested reasons for the inconsistent effects of values affirmations are racial composition of the school, classroom environment, dosage, and researcher or teacher implemented activities (Dee, 2015; Protzko and Aronson, 2016). However, Hanselman et al. (2017) failed to find significant effects of such moderators. Nonetheless, it is worth further exploring the benefits of values interventions for their potential to benefit minoritized students' math performance and achievement due to their unique relevance to minoritized students' experience with cultural mismatch in STEM majors. It just needs to be approached with more mindfulness to a holistic understanding of the student via PVEST.

Motivation interventions summary

Within a PVEST framework, all the various motivation interventions aim to address students' Net Stress by intervening on their meaning making in different ways. Self-efficacy interventions address students' confidence in their abilities, attribution interventions address students' attributions of their academic achievement or social belonging, and values interventions aim to highlight students' values. However, when and for whom these motivation interventions successfully reduce Net Stress is currently unclear, as demonstrated by the inconsistent effects on academic achievement (Kost-Smith et al., 2012). Shapiro et al. (2013) argue that not all interventions are likely to be successful under all situations of threat. Shapiro et al. (2013) found that role model interventions are helpful when the threat faced is targeting one's group, but that affirmation interventions are only helpful when the threat faced targets one's abilities. The fact that these individual motivation interventions are not consistently effective for minoritized students in general highlights the need for acknowledging the heterogeneity of this population. It is possible that if combined, motivation interventions could have greater efficacy due to the various sources of Net Stress they address. However, like for stereotype threat and math anxiety interventions there is a need for studies assessing the efficacy of these interventions specifically for undergraduate minoritized STEM students specifically with consideration to the key contributions of PVEST.

The interventions reviewed thus far generally do not adequately consider the sociocultural contexts and do not attempt to address the sources of Net Vulnerability in those contexts. One category of interventions has specifically focused on increasing undergraduate minoritized STEM students' math achievement by specifically intervening on the sources of their Net Vulnerability, collaborative learning interventions.

Collaborative learning in undergraduate mathematics

Over the decades, many institutions have enacted collaborative learning programs to support minoritized students in gateway courses, addressing the importance of social support, specifically peer support, to increase their STEM persistence (Lent et al., 2005). There are many models of near-peer academic support programs currently in use across the country, such as The Emerging Scholars Program (Asera, 2001), Supplemental Instruction (Dawson et al., 2014), Peer Assisted Learning (Arendale, 2014), Peer-Led Team Learning (Wilson and Varma-Nelson, 2016), more general learning communities (Carrino and Gerace, 2016; Johnson et al., 2023; Solanki et al., 2019), and various others. A key feature of such programs is the opportunity to engage with peers in active learning practices, specifically collaborative learning. Collaborative learning, as opposed to lecture-based teaching, has been shown to increase undergraduate student performance in STEM courses (Freeman et al., 2014; Springer et al., 1999) and to be beneficial specifically for minoritized students in STEM (Theobald et al., 2020). Group problem-solving exercises specifically are a promising collaborative learning technique shown to improve undergraduate student achievement in quantitative courses (Asiala et al., 1997; Dees, 1991; Ellington, 2005; Giraud, 1997; Keeler and Steinhorst, 1994). Overall, the benefits of collaborative learning interventions have been demonstrated for a wide range of mathematics courses, including but not limited to statistics (Giraud, 1997; Keeler and Steinhorst, 1994), calculus (Asiala et al., 1997), and university algebra (Ellington, 2005). Collaborative learning promotes achievement, productivity, self-esteem, intergroup attitudes, and positive attitudes toward learning (Springer et al., 1999). Collaborative learning environments likely lead to such positive outcomes for several reasons, including but not limited to having additional support for difficult content from peers, a less competitive environment, and an increasing sense of belonging (Springer et al., 1999; Hausmann et al., 2009).

The following section will focus on the Emerging Scholars Program, a collaborative learning workshop initially created by Uri Treisman at the University of California, Berkeley in the 1970s, since it was developed to specifically support minoritized students in calculus gateway courses (Asera, 2001; Fullilove and Treisman, 1990; Treisman, 1992). The core characteristic of this program is that minoritized students meet outside of lecture every week, working together to solve collaborative calculus problems with the support of a graduate student. The problems are difficult enough to motivate collaboration between students and promote critical thinking about the concepts without being overly challenging.

Several universities have adopted programs like the Emerging Scholars Program for university calculus, for example, the University of Texas at Austin, the University of Wisconsin at Madison, the University of Kentucky (Lexington), and Rutgers University (Asera, 2001; Fullilove and Treisman, 1990). The program was originally designed as a supplementary program (separate from formal courses; Asera, 2001) and had five aims: (1) to increase the time students spent on the subject concepts, (2) to provide students with the opportunity to explore challenging aspects of the subject, (3) to provide students an opportunity to interact more with peers, graduate students, and faculty, (4) to create a supportive student community, and (5) to incorporate academic advising.

The effectiveness of the Emerging Scholars program specifically has been demonstrated for African American and other minoritized students (Alexander et al., 1997; Bonsangue and Drew, 1995; Fullilove and Treisman, 1990; Moreno and Muller, 1999; Moreno et al., 1999; Peterson et al., 2013). Fullilove and Treisman (1990) used data from 646 African American students enrolled at the University of California, Berkeley, between 1973 and 1984, to compare outcomes for demographically similar workshop students to non-workshop students with comparable quantitative SAT scores. Overall, African American students who participated in the workshop were more likely to earn higher grades (B- or greater), less likely to fail the course, and persisted more in university than non-workshop African American students. Although these findings were promising, Fullilove and Treisman noted some limitations, including that workshop students were self-selected, and analyses did not sufficiently control for some demographic factors. However, several follow-up studies with methodological improvements have found similar benefits. Bonsangue and Drew (1995) assessed the efficacy of an Emerging Scholars program for African American and Latinx students enrolled in calculus courses. They found that workshop students received higher grades, had higher retention rates in STEM, and completed the calculus series more quickly than non-participating minoritized students. Furthermore, Moreno et al. (1999) found that when controlling for SAT scores, workshop participants (regardless of race/ethnicity) earned higher grades in the first calculus course than non–participants. Epperson et al. (2015) found that workshop students performed better on more abstract calculus problems than non-workshop students, suggesting that the collaborative workshop fosters a deeper and more flexible understanding of calculus concepts. Importantly, when Moreno and Muller (1999) statistically controlled for self-selection effects, workshop participation positively predicted student achievement and STEM major selection.

Application of collaborative interventions in out of class programs, like Emerging Scholars, is a way immediately to support minoritized STEM students and to surround them with demographically similar peers. Ideally, these collaborative learning techniques need to be imported into curriculum and course design for first-year math/calculus courses (Theobald et al., 2020), but this should not completely replace out of class programs such as Emerging Scholars. Out of class programs specifically for minoritized STEM students, and other informal spaces, offer a unique opportunity for minoritized STEM students to easily access peer support from one another, which is not possible in classes with low compositional diversity (Ong et al., 2018).

In summary, collaborative learning programs are promising for increasing minoritized student achievement in gateway calculus courses (see Theobald et al., 2020 for a large-scale analysis). These programs are also beneficial for other gateway math and science courses (Duncan and Dick, 2000; Peterson et al., 2013; Snyder et al., 2016; Wilson et al., 2012). However, because these programs incorporate multiple components (collaborative learning, advising, graduate student support, etc.), it is currently unclear which component of these programs is leading to these academic gains. But many other studies have demonstrated the specific benefit of collaborative learning activities, suggesting it is a crucial element (Asiala et al., 1997; Dees, 1991; Ellington, 2005; Giraud, 1997; Keeler and Steinhorst, 1994; Theobald et al., 2020).

PVEST and collaborative learning

Within the PVEST framework, collaborative learning interventions directly intervene on students' Net Vulnerability, which the previous interventions reviewed do not. First, interventions like the Emerging Scholars Program are made specifically with minoritized students' sociocultural contexts in mind to build a diverse community with the specific intention of providing social support for mathematics courses. Such contexts can buffer the vulnerability that minoritized STEM students may experience in math courses due to low compositional diversity by providing them with a mathematics context where they are more represented (Graham et al., 2013). In addition, collaborative learning interventions may be beneficial more generally because they require peers to explain concepts to one another (Fiorella and Mayer, 2013) and foster a deeper and more flexible understanding of calculus concepts (Epperson et al., 2015). Hence, the typical stress students experience when having difficulty understanding topics or having to solicit resources could be reduced when support from their peers is immediately available. Moreover, in such a context, the experience of "not knowing" becomes less isolating, increasing a student's sense of belonging (Hausmann, 2007; Hausmann et al., 2009) and reducing their Net Stress. Although collaborative learning programs were specifically created with the sociocultural context in mind and are helpful for many minoritized STEM students, not all minoritized STEM students may feel like they need such a program. For some, eliciting or receiving help may be perceived as a negative reflection of one's math skill (Graham and Barker, 1990). This again points to the need for understanding the individual differences students have, particularly with regard to their intersectional identities as presented by PVEST. In addition, the current work on collaborative learning interventions does not sufficiently account for the roles of other known sources of Net Stress, such as stereotype threat, math anxiety, and motivation discussed previously.

Discussion

Minoritized students pursuing STEM come from varying contexts and backgrounds with varying interests, perceptions, and experiences. Institutional supports for minoritized students in STEM need to better acknowledge these individual differences and the impact of the sociocultural and historical institutional systems on minoritized students' potential for success. The current literature shows that a wide variety of factors have measurable impacts on minoritized STEM students' success, but these factors are usually considered in isolation from one another, especially in the development/implementation of interventions, with little consideration or research on how they interact. PVEST provides a framework that can be used for us to better understand how these numerous factors could interact to influence minoritized students' experiences in STEM fields of study. Such a multi-dimensional framework is sorely needed when building interventions for minoritized STEM students. Without a holistic framework such as PVEST guiding this work, we will continue to conduct research and apply interventions in a manner that does not allow us to gain a full understanding of how these factors interact with each other to influence minoritized students' success in math gateway courses and how we can utilize such interventions to provide more comprehensive supports. PVEST demonstrates that we must consider: 1. the entire sociocultural context of the student (including their supportive contexts), 2. the individual differences between students in their meaning making/perception/interpretation of their context (e.g., the role of their intersectional identities), and 3. both the proximal (e.g., using adaptive coping responses) and distal (e.g., holding a math/STEM identity) outcomes and their role in the future experiences of the student. Although PVEST has not been used in the development of interventions, to our knowledge, it has been extensively studied as a valuable framework for studying pathways to success in minoritized populations (Cunningham et al., 2023).

One conclusion of this review is that there is a dearth of research specifically focusing on the efficacy of existing interventions specifically for undergraduate minoritized students in STEM contexts more generally and math contexts specifically. Although stereotype threat, math anxiety, and motivation are known predictors of math achievement and performance, research on how their associated interventions specifically benefit minoritized students' math achievement and STEM persistence is limited, with many interventions studied more extensively with general academic achievement, K-12 students, or with samples of unknown demographic composition. Indeed, attention has been brought to the limited focus given to race and ethnicity in motivation research, and likely psychology in general (Usher, 2018; Zusho and Kumar, 2018). Furthermore, there is little consideration of issues of intersectionality between race/ethnicity, gender, and socioeconomic background in the current literature on these interventions (Harackiewicz et al., 2016). Much more research on the efficacy of such interventions specifically for minoritized students' math achievement and STEM persistence is needed.

There is also a need for research testing the application of PVEST to undergraduate minoritized STEM students. The majority of STEM interventions for gateway math courses are derived from theoretical frameworks related to self-organization theories or theories about individuals' perceptions of themselves (Harackiewicz and Priniski, 2018). These theoretical frameworks work well for the development of targeted interventions developed for a specific context, population, and set of tasks. However, as soon as the intervention is applied in a different context it fails, because they were not adjusted for the new context (Gaspard et al., 2023). Generally, these types of interventions assume that a student has risk factors, but they often do not consider their protective factors. Thus, a developmental framework that acknowledges protective factors among minoritized populations may better support our understanding when interventions are not effective at changing student outcomes or there is a great deal of variability in student responses to interventions. PVEST allows us to understand how, why, and for whom certain interventions are effective in a way current approaches do not. Future intervention research utilizing PVEST can offer us insight into what intervention conditions and moderators contribute to positive outcomes and how different types of interventions interact together.

In addition, to make the current math achievement interventions more aligned with the PVEST framework, consideration of how different interventions can complement each other is needed. Stereotype threat, as discussed earlier, is a stress response arising when minoritized students fear confirming a negative stereotype about one of their identities (Spencer et al., 2016; Steele and Aronson, 1995). Interventions for stereotype threat are varied and consist of addressing minoritized students' beliefs or resilience (Liu et al., 2021), addressing the impact of stereotype threat on Net Stress. Math anxiety, defined as the tension and apprehension elicited by math contexts, is similar to stereotype threat in that it too impacts available cognitive resources by increasing worry (Ashcraft and Kirk, 2001; Johns et al., 2008). Most current math anxiety interventions involve helping students engage in relaxation techniques (Chang and Beilock, 2016). Motivation is made up of a wide range of constructs generally relating to the beliefs, values, and goals that guide students' actions and persistence (Wentzel et al., 2009). Most motivation interventions target students' confidence in a domain or task, their attributions of their academic performance or social belonging, or their values (Lazowski and Hulleman, 2015). Each of these interventions targets various sources of Net Stress or how students experience and interpret their undergraduate math course, or their with Reactive Coping. Although it is important to consider the different roles that different sources of Net Stress play none of these interventions focus on systemic factors, such as lack of compositional diversity. Collaborative learning interventions on the other hand, specifically focus on trying to address this source of Net Vulnerability by creating environments where minoritized students can feel more represented, but more interventions that target Net Vulnerabilities are needed.

There are many factors that contribute to minoritized STEM students' Net Vulnerability in university-level mathematics or STEM that should be considered in a PVEST-based approach to improving minoritized students' university math outcomes (e.g., funding inequities, faculty biases, assessment practices, enrollment criteria, etc.) For example, Price (2010) found in a large-scale study of university students that when Black students have at least one Black instructor in a STEM field, they are more likely to pursue or stay in a STEM major (this effect is also true for female students and instructors). Importantly, numerous correlational studies point to the importance of identification with mathematics (and STEM) as well as positive racial identity for STEM (Chavous and Drotar, 2016; Yu et al., 2016), and interventions that specifically address identity have been found effective for younger students (Oyserman, 2015). Finally, involvement in undergraduate research for STEM majors has a known impact on STEM persistence and mathematics performance and achievement in first-year math courses (Hernandez et al., 2013). Such work is necessary to elucidate the actual interactions between all the numerous factors that influence minoritized STEM students' success.

To fully address the underrepresentation of minoritized students in STEM, institutions not only need to focus on improving the persistence of already existing STEM majors, but they also need to increase the recruitment of minoritized students into STEM majors. To fully address diversity, equity, and inclusion of minoritized students in STEM majors, educational institutions need to look beyond immediate interventions and student supports and need to make long-term institutional changes to dismantle the structures, stereotypes, and the negative climates that lead to underrepresentation in STEM in the first place (e.g., funding inequities, faculty biases, assessment practices, enrollment criteria, etc.; Estrada et al., 2016; Gutiérrez, 2013, Kezar et al., 2022; López et al., 2022; Museus, 2014; Ridgeway and McGee, 2018; Tinto, 2012). Most interventions that have been studied so far are designed to prepare the student to persist despite the obstacles presented to them at their institution or their program but persisting in STEM courses and majors is difficult when one's society, institution, and/or department culture sets one up to fail.

For there to be lasting change, there not only needs to be immediate comprehensive supports put in place, but educational administrators and policymakers need to enact top-down institutional change to reevaluate and modify the greater culture that originally led to the systematic dropout of minoritized students in STEM (Estrada et al., 2016; Kezar et al., 2022; Museus, 2014). Enacting institutional and societal change is a complex and major undertaking that is often sluggish (López et al., 2022), but it is necessary [for a discussion on how institutions can begin to enact institutional change, see Estrada et al., 2016]. Such changes will require substantive shifts in approaches to education and research (Gutiérrez, 2013; Ridgeway and McGee, 2018). Although a greater discussion of systemic changes is beyond the scope of this paper, there is a need to couple the interventions that can be immediately applied with greater institutional efforts to address systemic issues.

Conclusion

Although there are still many questions left to be addressed, institutions and degree programs can act immediately to increase minoritized students' success and persistence in STEM fields by developing interventions that address the key contributions of PVEST by considering: 1. the entire sociocultural context of the student (including their supportive contexts), 2. the individual differences between students in their meaning making/perception/interpretation of their context (e.g., the role of their intersectional identities), and 3. both the proximal (e.g., using adaptive coping responses) and distal (e.g., holding a math/STEM identity) outcomes and their role in the future experiences of the student. Specifically, this would mean going beyond individual-focused interventions and providing these students with more environmental supports, helping students build more positive interpretations of their contexts, and preparing them with adaptive coping strategies to help them navigate their STEM degrees. Each individual student will face their own unique set of obstacles; some will feel isolated while others might be struggling with crippling mathematics anxiety. In order to help different students succeed, minoritized student support programs should be multidimensional and target the varied components that are known to influence student STEM achievement. To give minoritized STEM students the best chances of success, it is important not to focus on just providing them one tool over another, but to provide them with a whole arsenal of supports to help them get through their academic journey.

In memoriam

This paper is in loving memory of J. Frank Yates. His lifetime dedication to diversity, equity, and inclusivity work, especially for Black youth, has served as an inspiration to many and specifically motivated the writing of this paper.

Author contributions

AI: Conceptualization, Writing – original draft, Writing – review & editing. SM: Conceptualization, Writing – original draft, Writing – review & editing. JY: Conceptualization, Resources, Supervision, Writing – original draft, Writing – review & editing. PS: Writing – original draft, Writing – review & editing, Conceptualization, Supervision.

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