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When perceived similarity overrides demographic similarity: examining influences on STEM students' developmental mentor networks

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Abstract

Background While dyadic faculty–mentored relationship research currently saturates the mentoring literature, recent developments suggest the need for a broader consideration of a student's mentor network. Research taking a network approach may provide deeper insights into the formation and benefits of mentorship for undergraduate students in science, technology, engineering, and mathematics (STEM) disciplines. Utilizing Developmental Mentor Network Theory and ego-centric social network analysis, this pre-registered study evaluates how the characteristics of mentees and mentors relate to both the content of support and structure of mentor networks in a large sample of White and Hispanic/Latino(a) STEM undergraduates across 12 universities.

Results Results were nuanced but showed that perceived psychological similarity with their mentor(s) predicted both dyadic and network average levels of mentor support (i.e., psychosocial, career, role modeling) and relational satisfaction. Furthermore, results point to homophily and engagement in undergraduate research effects on mentor network structures.

Conclusions These findings highlight the importance of using a network approach to deepen our understanding of the factors (e.g., psychological similarity) that may influence the formation and maintenance of robust and diverse supportive mentoring networks.

Keywords Mentoring, STEM, Undergraduates, Mentor network, Similarity

Academic institutions are actively working to better support and retain persons from minoritized groups (e.g., women, African Americans) to meet the demands for developing a more diverse and skilled workforce in the fields of science, technology, engineering, and mathematics (STEM; Estrada et al., 2016; Handelsman et al., 2022; Thiem & Dasgupta, 2022). Recent reports from the National Science Foundation highlight that trends in undergraduate STEM degree conferrals have increased for students from these historically under-represented (HU) groups over the last decade (National Center for Science & Engineering Statistics [NCSES], 2023). However, many populations are still significantly under-represented in STEM fields compared to their share of the total U.S. population (NCSES, 2023). For example,

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Hispanic/Latino(a)[1] undergraduate STEM degree conferrals have more than tripled since 2011, yet when compared to their 22% representation in the total U.S. population, Hispanic/Latino(a) students still only represent about 12–15% of all STEM undergraduate degree conferrals. These demographic differences in pursuit and degree attainment portend future disparities in the STEM workforce. Disparities in STEM fields and the persistence of systemic barriers contributing to these differences merit the attention of institutions and organizations to implement research-based practices that support students from HU groups in STEM.

Experiences of many historically under-represented STEM students

While students from HU groups pursue undergraduate STEM degrees at the same rate as their White counterparts, graduation rates in these fields are significantly lower for students from HU groups (Hurtado et al., 2009; NCSES, 2023). These inequities have been attributed to the historical pervasiveness of systemic barriers within higher educational opportunities, such as stereotypes and discrimination, inequities in access to high-quality pre-college education, and an absence of culturally relevant role models and mentors (Clotfelter et al., 2023; Milner, 2012). Systemic barriers can create an unwelcoming environment, negatively impacting HU students' sense of belonging in the STEM field they aspire to join, and ultimately contribute to limited diversity in higher education (Deemer et al., 2022; Estrada et al., 2016; Johnson, 2012; Lubienski & Gutiérrez, 2008; Mishra, 2020; National Academies of Sciences Engineering & Medicine [NASEM], 2016; Park et al., 2022; Thiem & Dasgupta, 2022).

Higher education scholars have worked to explicate systemic barriers by analyzing institutional successes and failures. Research shows that increasing high-quality social support—that is, the social interactions or relationships that convey instrumental or emotional support can promote student success, particularly for students from HU groups (Estrada et al., 2016; Hobfoll & Stokes, 1988; Laireiter & Baumann, 1992; Thiem & Dasgupta, 2022). Social support can come from formal programs (e.g., summer bridge programs; Palid et al., 2023), from family, particularly for students from low-income, first-generation, or HU backgrounds (Fernández et al., 2023; Mishra, 2020; Starr et al., 2022), as well as from on-campus social supports through faculty and near-peer mentoring (Estrada et al., 2016, 2018a, 2022; Pedersen et al., 2022; Wu et al., 2022). This study examines one such social support, mentoring relationships, among White and Hispanic/Latino(a) undergraduates in STEM majors.

Mentoring undergraduate students in STEM

Research indicates that mentorship, that is, relationships where a more experienced person (i.e., mentor) actively supports the personal and professional development of a less experienced person (i.e., mentee), can be part of the solution to recruiting and retaining diverse students into STEM fields (National Academies of Sciences Engineering & Medicine [NASEM], 2019). Mentoring relationships can support undergraduate students academic success and career development (Crisp & Cruz, 2009; Jacobi, 1991; NASEM, 2019). Furthermore, supportive relationships help students integrate into their STEM academic community, particularly for students from HU groups (Byars-Winston et al., 2015; Lisberg & Woods, 2018; Tise et al., 2023). For example, students mentored by a faculty member develop significantly stronger professional identities, sense of belonging, self-efficacy, and positive attitudes in their STEM fields compared to students without a faculty mentor (Kuchynka et al., 2023). Yet, there can be significant inequities in who has *access* to high-quality mentor support, with some studies indicating that students from disadvantaged backgrounds are less likely to receive support (Garringer & Benning, 2023; Martin et al., 2014, 2020; Raposa & Hurd, 2021). Because systemic barriers in higher education can limit student's opportunities for access to social support (Estrada et al., 2016; Thiem & Dasgupta, 2022), investigations into the conditions and contexts that impact the quality of mentorship support for individuals from diverse backgrounds in STEM are critical (see recommendations 9.4–9.5 in the NASEM 2019 report).

The 2019 NASEM report titled "Science of Effective Mentorship in STEMM" also recommended researchers assess the existence and impacts of multiple mentorship structures for undergraduate mentees (recommendations 5.1–5.4; NASEM, 2019). A major limitation of the extant literature is its near-exclusive focus on the relationship between a primary mentor and the undergraduate mentee (i.e., the focus on *dyadic mentoring relationships*; Montgomery & Page, 2018). The preponderance of research in undergraduate STEM contexts has focused on dyadic mentoring relationships between a faculty mentor and a student mentee in the context of an undergraduate research experience (NASEM, 2019).

[1] The use of the term "Hispanic/Latino(a)" throughout the manuscript was reflective of the demographic questions asked of participants, as well as linking our terminology to the university context where student participants were attending school at one of multiple Hispanic-Serving Institutions (HSI). This term may (or may not) accurately reflect the ethnic and/or racial identities of all student participants of the study (e.g., Latinx), but is consistent with institutional data at the relevant universities (American Psychological Association [APA], 2022; Villanueva Alarcon et al., 2022).

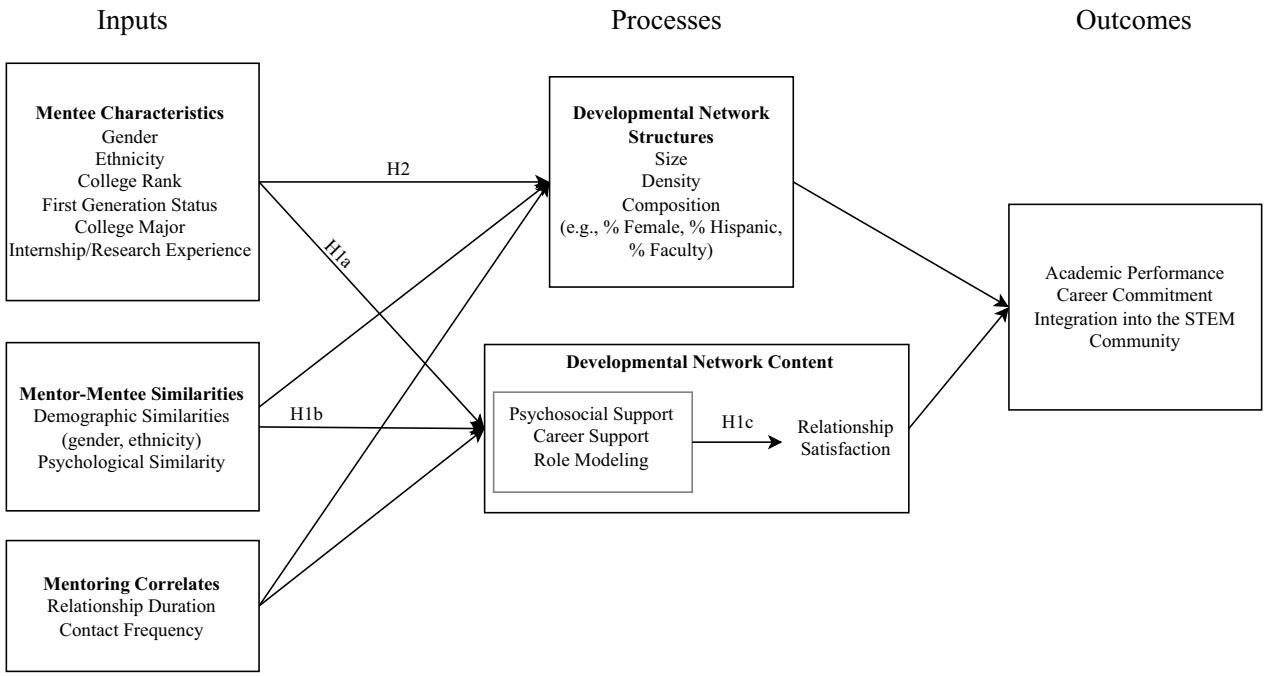

Fig. 1 Developmental mentor network hypothesized relationships

Theoretical advancements in and critiques of the mentoring literature suggest that a holistic assessment of a student's network of mentors may provide deeper insights into the nature and benefits of mentorship (Dobrow et al., 2012; Higgins & Kram, 2001). Furthermore, the mentor network approach can address critical questions about the conditions and contexts that impact the quality of those relationships among diverse undergraduates in STEM (Higgins & Kram, 2001; Martin et al., 2014, 2020; Montgomery & Page, 2018; NASEM, 2019). Therefore, the current study aimed to assess and predict characteristics of mentor networks, as well as the quality of mentorship support received by White and Hispanic/Latino(a) undergraduates in STEM.

Theoretical framework

The Process-Oriented Model of Mentoring (POMM), developed by Eby et al. (2013) from a large multidisciplinary meta-analysis, is a theoretical framework that describes the inputs to, processes of, and benefits from dyadic mentoring relationships. The POMM can serve as an important foundation for understanding the conditions and contexts that promote high levels of mentor support and relationship quality, which aligns with key investigation recommendations by the mentoring community (e.g., Recommendation 9.5 "Scholars should investigate how different aspects of mentor–mentee sociocultural similarity may help shape mentorship outcomes…"; NASEM, 2019, p. 14).

Concerning *inputs*, the POMM suggests that a variety of mentor and mentee characteristics (e.g., race/ethnicity), as well as mentor–mentee similarities (e.g., racial similarity), can influence mentoring processes in terms of the content and strength of mentoring support received by the mentee (Fig. 1: paths indicated with H1a and H1b; controlling for correlates such as the frequency of mentee–mentor contact and the duration of their relationship).

Concerning mentoring *processes*, the content of mentoring support has been operationalized in terms of three functions that lead to overall relationship quality: (1) *psychosocial support* by providing counseling, encouragement, and social guidance, (2) *career support* through developing technical skills and offering sponsorship, and (3) *role modeling support* by exemplifying achievable success and providing a pathway to achieve such success (Eby et al., 2013; Jacobi, 1991; Lockwood & Kunda, 1997). These support functions should promote the mentee's overall satisfaction with the mentoring relationship (Fig. 1 H1c), which in turn should influence the *benefits* of mentoring, such as academic success and persistence (Eby et al., 2013). While the POMM provides a helpful framework, relatively few of the empirical studies incorporated into the meta-analysis examined mentoring relationships among undergraduates in STEM contexts. We, therefore, briefly review evidence and gaps in the literature linking potential inputs to the quality of mentoring support.

POMM inputs to mentoring support in STEM

Research has focused on a variety of individual and programmatic characteristics that influence the formation of high-quality relationships between a mentor and undergraduate mentee (Crisp & Cruz, 2009; Jacobi, 1991; NASEM, 2019), but there has been a sustained interest in mentor–mentee shared similarities. Social science theory and research suggest that social relationships can be primed for attraction, liking, and friendship by homophily (i.e., the principle that people are more likely to connect with others similar to themselves; Byrne, 1971; McPherson et al., 2001), along dimensions such as demographic similarity (e.g., race, gender; Blake-Beard et al., 2011), experiential similarity (e.g., common educational, career, or life experiences; Harden et al., 2009), or psychological similarity (e.g., attitudes, values; Hernandez et al., 2017). Research on faculty mentoring in STEM has found mixed results linking the demographic characteristics of mentors, mentees, or their demographic similarity with mentoring support and relationship satisfaction (Blake-Beard et al., 2011; Estrada et al., 2018a; Hernandez et al., 2017, 2023a; Kuchynka et al., 2023; Morales et al., 2021; Pedersen et al., 2022; Robnett et al., 2019). For example, recent studies have found negligible associations between demographic similarities (e.g., same-race vs. different-race dyads) and mentorship support among African American and White STEM undergraduates (Hernandez et al., 2017, 2023a). By contrast, others have found small positive associations between the quality of mentorship support and either mentor–mentee gender similarity (Morales et al., 2018) or similarity as being from a racial/ethnic minority group in STEM (although not necessarily from the same racial/ethnic group; Blake-Beard et al., 2011; Ortiz-Walters & Gilson, 2005). Still, another study found small positive associations between the quality of mentorship support and having a same race/ethnicity faculty mentor among Hispanic/Latino(a) mentees in STEM (Pedersen et al., 2022). Although these studies provide information on faculty–student mentoring relationships, their focus on dyadic relationships misses the full scope of mentoring relationship networks that support students aspiring to STEM degrees and careers. Assessing the network of mentors from various personal and professional arenas is needed to develop a more nuanced characterization of the impact of demographic similarities on the content and strength of support.

Consistent with the POMM, studies of faculty–student mentoring in STEM show a strong positive association between mentor–mentee psychological similarity and the content and strength of mentorship support (Hernandez et al., 2017, 2023a; Pedersen et al., 2022; Turban et al., 2002). That is, students who perceive that they are similar to their mentors in terms of outlook, perspective, and values report higher levels of mentor support and overall relationship satisfaction with their mentors. These patterns are consistent within dyadic mentoring relationships, particularly for undergraduates from HU groups (Hernandez et al., 2017, 2023a; Pedersen et al., 2022), where opportunities for demographic matches with faculty are constrained due to inequities throughout the academy. Less is known about the consistency of these patterns on factors that influence mentorship support and satisfaction *across* a network of mentors for undergraduate students in STEM, specifically for those from diverse backgrounds.

Developmental mentor networks

While decades of research have highlighted the significant role a single *primary* mentor can play, this dyadic focus has yet to capture the extent to which multiple mentors from a variety of backgrounds and social arenas provide support to a mentee. Mentoring research in college contexts have only recently begun to shift from a dyadic focus to a broader perspective examining how networks of mentors provide support (Aikens et al., 2016, 2017; Dobrow et al., 2012; Haggard et al., 2011; Hernandez et al., 2023b; Joshi et al., 2019). While frameworks like POMM serve as dyadic theories, the developmental network theory (DNT) integrates mentorship and social network theories to acknowledge that individuals can have multiple mentors and that these multiple mentors may be connected to one another (Dobrow et al., 2012; Higgins & Kram, 2001; Perry et al., 2018). Moreover, DNT provides an important distinction between the content of support (e.g., psychosocial support) and the social *structures* of a mentor network. Social structures of mentorship networks include the number of mentors in the network (i.e., size), the number of unique, nonredundant connections in the network (i.e., effective size), the degree of connectedness amongst mentors in the network (i.e., density), and the composition in terms of personal/professional roles and range. Importantly, the content and structure of mentorship networks represent the social capital (i.e., access to information, support, and resources) that is available to a mentee, which is critical to integration into a professional community (Martin et al., 2014; Mishra, 2020; Schwartz et al., 2018; Skvoretz et al., 2020).

Similar to the POMM, DNT hypothesizes that mentor and mentee characteristics, as well as mentor–mentee similarities, should influence both the content and structures of mentorship networks (Fig. 1, H2; Borgatti et al., 2018; Dobrow et al., 2012; Higgins & Kram, 2001). Mentor network research suggests the need for diverse networks, as specific members of a student's network may provide different kinds of support (Deanna et al., 2022;

Keller & Lindwall, 2020). For example, family and community members might provide social support for students, while institutional networks (e.g., faculty, learning communities) might provide more informational social capital (Martin et al., 2014; Mishra, 2020), particularly for students from under-represented backgrounds (Lukács & Dávid, 2023; Mishra, 2020). Research is beginning to inform on the kinds of support provided to undergraduate mentees from varying sources, but more research is needed to understand how to best support students in STEM disciplines, particularly those from HU groups.

DNT and STEM undergraduates

Within the context of STEM education, few studies have examined the structures and qualities of developmental mentors, particularly for students from under-represented backgrounds. One relevant line of research, which examined the relationships between undergraduates, graduate students, and faculty, showed that varying downstream impacts of integration into STEM disciplines were based on triadic structures (Aikens et al., 2016, 2017; Joshi et al., 2019). This research found variations in undergraduate(mentee)–graduate(mentor)–faculty(mentor) triadic structures based on mentee demographics (e.g., gender and race/ethnicity), such that students from HU groups had increased contact frequency with their mentors, which lead to an increased likelihood that these mentor networks were connected amongst all three members of the network (undergrads, graduate students, and faculty; Aikens et al., 2017). Furthermore, undergraduate students with any connection to a graduate student reported higher levels of identification as a scientist, an outcome that increased for students in a closed triad (connections amongst all three members of the network; Aikens et al., 2017). Similarly, a recent study examined the mentor networks of diverse undergraduate women in science and found that the size of their networks and the density of connections among mentors were related to gains in science identity and persistence in science (Hernandez et al., 2023b). Such research suggests the impact of diverse, connected multi-mentor networks in promoting academic and professional success for STEM students (Deanna et al., 2022; Haeger & Fresquez, 2016; Keller & Lindwall, 2020; NASEM, 2019).

In summary, research has only begun to inform our understanding of the broader context of mentorship networks and social capital available to undergraduate mentees. While studies of triadic relationships between undergraduates, graduate students, and faculty members have begun to explore the network aspects of mentoring, these studies are limited in that they address mentorship limited to on-campus mentors. It is important to expand upon this work with theory-guided research on the factors associated with the formation of strong, supportive, and diverse mentorship networks among both undergraduate minority and majority STEM students. To date, no study has characterized developmental mentor network support processes and network structures in the context of STEM undergraduates, specifically examining similarities and differences among students from White and to Hispanic/Latino(a) demographic groups. This utilization of social network methodologies aligned with DNT will allow us to describe student mentor network characteristics and predict the type of support, strength of support, and network structures from a set of theory-guided influencing factors.

Current study

The primary goals of this study were to address gaps in the mentoring in STEM literature by describing the characteristics of undergraduate students' mentorship networks and to test the influence of theoretically meaningful factors on the characteristics of mentor networks. This study examines undergraduate mentorship networks in a large and diverse sample of Hispanic/Latino(a) and White undergraduates in STEM majors attending college at one-of-twelve public Hispanic-Serving Institutions (HSI) on the West Coast of the U.S. The uniqueness of our approach and of the sample are important because not only do we utilize developmental networks (multiple mentors), but mentor networks are composed of faculty, peers, post-doctorates, and mentors from outside of the university.

This study addresses gaps in the mentoring in STEM literature by addressing several interrelated questions. *First*, what are the characteristics of undergraduates' mentor networks in terms of the type and strength of support provided, as well as structural features such as size, composition (e.g., gender composition of their network), and interconnectedness? *Second*, do any of the characteristics of mentor networks (i.e., supports or structures) vary depending on the characteristics of the students or their mentor(s)? *Third*, are mentee–mentor shared similarities, in terms of demographic or psychological similarity, associated with the qualities of mentoring support? *Fourth*, does the quality of support influence overall satisfaction with the mentoring relationship? Informed by POMM and DNT theories, we pre-registered (OSF.io: osf.io/f2rv8) several formal hypotheses associated with questions 2–4 from above.[2]

[2] Research question one is descriptive in nature and thus a hypothesis was not relevant.

Influences on the content of mentor support

H-1a. Concerning mentor characteristics (i.e., race/ethnicity, gender, career stage), we hypothesized the following: Mentor characteristics will predict developmental mentorship network content of support, controlling for other factors such as mentee characteristics (e.g., race/ethnicity) and mentoring relationship correlates (i.e., relationship duration and contact frequency).

H-1b. Concerning mentor–mentee shared similarities (e.g., same-gender), we hypothesized the following: Similarity (vs. dissimilarity) will predict developmental mentorship network content of support, controlling for other factors.

H-1c. Consistent with the POMM, we predicted that the three types of support (i.e., psychosocial, career, and role modeling) would positively predict relationship satisfaction, controlling for other factors.

Influences on the structure of mentor networks

H-2. We hypothesized that mentee characteristics (i.e., race/ethnicity, gender, college rank, major, university, first generation status, internship/research experience) and mentoring correlates will predict network structures (e.g., size, composition).

Methods

Participants

The current study draws a sample from a larger study titled "My College Pathways," which focused on the professional development of White (non-Hispanic) and Hispanic/Latino(a) undergraduates pursuing STEM majors and careers. White (non-Hispanic) and Hispanic/Latino(a) (of any race) undergraduate STEM students in their junior and senior years of college from 12 universities on the West Coast of the U.S. were recruited to participate in a longitudinal study. The project was a 5-year study aimed at evaluating how personal and professional identities support academic persistence and success in STEM. Overall, $N = 1{,}310$ students from 12 universities consented to participate. The universities were all public HSIs and were either Carnegie Classification R2 (Doctoral; 25%) or Masters-serving (75%) universities.

The present study comes from a cross-sectional point in the 5-year study, captured during the spring of 2021, the third semester of the longitudinal study, when mentor networks were measured. Of the overall sample, $n = 935$ undergraduates participated in the Spring 2021 survey ($n = 250$ non-responders, $n = 125$ graduates/no longer enrolled). Among the undergraduate students who participated, 533 indicated they did not have a mentor, and 402 identified having at least one mentor. Of those with at least one mentor, 80 were removed due to missing responses on questions pertaining to their mentors (e.g., missing career status), leaving a total analytic sample of $n = 322$ (see Additional file 1: Table S1 notes for additional sample characteristics).

The analytic sample ($n = 322$) was made up of White and Hispanic/Latino(a) undergraduate students (48% and 52%, respectively; see Table 1). Students included in the sample were currently enrolled in undergraduate studies (16% juniors, 76% seniors, 8% 5th year) and were majoring in Science (48%; e.g., Biology, Chemistry, Physics), Computer Science (9%), Engineering (32%; e.g., Aerospace, Electrical, Mechanical), Mathematics (6%), Software Engineering (3%), or in a Non-STEM or STEM-related major (2%). Most students who identified having a mentor had more than one mentor in their network (71% of the sample with at least one mentor). Additional sample characteristics broken down by student ethnicity for the analytic sample ($n_{mentees} = 322$) and the mentors in their networks ($n_{mentors} = 822$) can be found in Table 1.

Procedures

Potential participants for this 5-year longitudinal project, titled "My College Pathways," were recruited in the Fall of 2019 by requesting STEM major email listservs from the 12 university campuses and sending out recruitment fliers and videos via email. Snowball sampling was utilized after participants completed the initial screening survey. Participants completed a brief online screening survey to provide informed consent and collect demographic information, academic status, and contact information. Participants who met the study inclusion criteria were invited to participate in the longitudinal study (i.e., being 18 or older years of age, undergraduate rank of junior or senior status, majoring in a STEM discipline, self-identifying as being of European and/or Hispanic/Latino(a) descent, and currently enrolled at one of the 12 universities involved in the study). Invited participants were sent follow-up online surveys each semester thereafter about their college experiences, identities, mentorship networks, and career aspirations via Qualtrics and received a small incentive ($20 per survey). Follow-up communications and surveys follow the Tailored Panel Management approach to ensure high response rates over time (Estrada et al., 2014). Data for the current study come from the Spring 2021 survey when the developmental mentorship network questionnaire was administered. All procedures were approved by a local Institutional Review Board (Project IRB#1450129-2).

Table 1 Summary of descriptive statistics for mentees ($n = 322$) and mentors (observations = 822) characteristics (reported by the mentee)

	White ($n = 155$)		Hispanic/Latino(a) ($n = 167$)		Chi-square difference test
Variable	***n***	**(%)**	***n***	**(%)**	
Mentee characteristics					
Mentee Gender					
Woman	76	49.0	94	56.3	1.70
Man	78	50.3	72	43.1	1.67
Other	1	0.65	1	0.60	.003
Mentee Race/Ethnicity (Choose all that apply)					
African American/Black	0	0	1	31	.93
Asian	6	3.9	5	3	.19
Hawaiian/Pacific Islander	1	.6	1	.7	.003
Hispanic/Latino(a)	11	7.1	167	100	280.66***
Native American/Native Alaskan	0	0	3	1.8	2.81
White	155	100	14	8.4	258.87***
Other (Please Specify)	5	3.2	1	0.6	3.03
Multi-Racial/Multi-Ethnic	19	12.3	23	13.8	.35
Major					
Science	72	46.5	82	49.1	.23
Computer Science	14	9.0	15	8.98	.0002
Engineering	50	32.3	52	31.1	.05
Mathematics	8	5.2	12	7.2	.57
Software Engineering	8	5.2	3	1.8	2.76
Non-STEM/STEM-Related	3	1.9	3	1.8	.01
Class Rank					
Junior	29	18.7	21	12.6	2.31
Senior	114	73.6	130	77.8	.81
5th Year	12	7.7	16	9.6	.34
First Generation	39	21.2	120	72.9	70.12***
Undergraduate Research Experience	84	54.19	106	63.47	2.86
Internship Experience	64	41.29	84	50.3	2.63
Mentor Network Size					
1 Mentor	45	29.0	47	28.1	.03
More than 1 Mentor	110	71.0	120	71.9	.03
Mentor characteristics					
Mentor Race/Ethnicity					
White	270	71.2	135	30.5	135.81***
Hispanic/Latino(a)	39	10.3	214	48.3	138.56***
Other Ethnicity	70	18.5	94	21.2	.97
Matched Race/Ethnicity	270	71.2	214	48.3	44.37***
Mentor Gender					
Woman	164	43.3	218	49.2	2.90
Man	213	56.2	225	50.8	2.40
Other/Unknown	2	0.53	0	0	2.34
Matched Gender	236	62.3	254	57.3	2.06
Career Status					
Faculty	121	31.9	180	40.6	6.67*
Postbac	32	8.4	31	7.0	.60
Undergraduate	68	17.9	55	12.4	4.90*
Outside of the University	158	41.7	177	40.0	.25

Students were nested within 12 universities (7.8% university 1, 7.8% university 2, 18.1% university 3, 13.3% university 4, 8.7% university 5, 12.9% university 6, 7.1% university 7, 3.3% university 8, 6.3% university 9, 4.2% university 10, 5.3% university 11, 5.4% university 12)

* $p \leq .05$, ** $p < .01$, *** $p < .001$

Measures

Mentee demographic and academic characteristics

Participants self-reported their demographic and academic characteristics, such as gender identity (Female/Male/Other[3]), race/ethnicity identity (White [non-Hispanic/Latino(a)] or Hispanic/Latino(a) [of any race]), status as a first-generation college student, university affiliation, major, college rank (Junior/Senior), and if they have ever participated in any undergraduate research experience or internship (i.e., "Have you ever had an internship prior to Spring 2021?;" Yes/No, coded into dummy-variables) in Fall 2019 (semester 1 of the study). Regarding race/ethnicity, participants were asked what their race/ethnicity was and could select multiple options (see Table 1). Following, they were asked "With which of the following racial/ethnic groups do you most strongly identify?" (e.g., White, Hispanic/Latino[a]). The demographic variables of interest were dummy-coded to indicate: men (vs. women), Hispanic/Latino(a) (vs. White), and first-generation college status (vs. continuing generation). The control variables, university affiliation, major, college, rank, and Research/internship participation were also dummy-coded for analyses. When dummy-coding, the reference group was selected on the three best practice principles of (a) identifying a comparison group of interest, (b) having the reference group be a well-defined group, and (c) having the reference group be relatively large (Cohen et al., 2003; D'ignazio & Klein, 2020).

Developmental mentor network

Participants completed up to 82 items in the developmental mentor network questionnaire (Hernandez et al., 2023b). Participants were asked to read a brief definition of a mentor:

> *A mentor is a professional relationship where you work with someone over time to support personal, academic, and career growth and success. Mentors might include peers, professors/faculty members.*

With that definition in mind, participants were asked if there was a person (or persons) they considered to be a mentor (Yes, No). Participants who answered "Yes," were asked a series of follow-up questions about the person(s) that provide them with mentorship support (i.e., name interpreter questions). Furthermore, participants who identified two-or-more mentors in their network were asked follow-up questions about whether or not the mentors knew one another (Yes, No; i.e., inter-relator questions).

Mentor demographic characteristics First, participants were asked to name each of the persons they considered to be a mentor ("Please name up to 5 people that provide you with direct mentorship support [i.e., guidance, assistance, and encouragement] related to attaining your goals. Please provide only initials or first name."). Second, participants reported their perceptions of each mentor's gender identity[3] (Male, Female, Other, Unknown), race/ethnicity (Hispanic/Latino(a), Black/African American, White, Hawaiian/Pacific Islander, Native American/Native Alaskan, Asian, Other), and career stage (University Faculty, Postdoc, Graduate Student, Undergraduate Student, Professional working outside of the university, Other). We note that these measures about the mentor are based on the perceived identifications of mentor demographics by the mentees, which relies on either stereotypical expressions or deep relational knowledge of the mentor's demographics and is typical of ego-centric social network methods (Perry et al., 2018). The demographic variables were dummy-coded to indicate: men (vs. women) and other/unknown (vs. women); Hispanic/Latino(a) (vs. White), other/unknown race/ethnicity (vs. White); and faculty (vs. outside the university), undergraduate (vs. outside the university), and post-baccalaureate (vs. outside the university).

Psychological similarity To measure participants' perception of similarity with each of their mentors, one item from the Perceived Similarity scale (Turban & Jones, 1988) was used. Participants rated their agreement with "[Mentor Name] and I are similar in terms of our outlook, perspectives, and values" on a scale of 1 (not at all) to 7 (to a large extent). Higher values indicated stronger levels of psychological similarity. Because participants were completing questions about each mentor in their network, only one item per construct was used to reduce the burden on survey respondents. The single item for this construct (and others related to mentoring relationship qualities) was chosen based on item content and strength of association with the latent constructs from prior factor analyses (Hernandez et al., 2017; Pedersen et al., 2022).

Mentorship psychosocial, career, and role modeling support To measure participants' perception of support from each of their mentors, two items from the Global Measure of Mentoring Practices (historical internal consistency $\alpha = 0.95$ and $\alpha = 0.75$, respectively; Dreher & Ash, 1990; Tenenbaum et al., 2001) and one item from the Role Model Identification scale (Hoyt et al., 2012) were used. Specifically, participants rated their level of

[3] The use of the term "Female/Male" was reflective of the demographic options provided to participants intended to capture their gender identity. In future works, the authors would use more inclusive terms to capture gender identity (e.g., man, woman, genderqueer, gender-nonconforming, transgender; D'ignazia & Klein, 2023).

agreement on a scale of 1 (not at all) to 7 (to a large extent) to one item about psychosocial support (i.e., "[Mentor Name] has conveyed empathy for my concerns or feelings I have discussed with him or her."), one item about career support (i.e., "[Mentor Name] has helped me learn new skills, finish assignments/tasks, or meet deadlines that otherwise would have been difficult to complete.") and one item about role modeling (i.e., "I identify with the life and accomplishments of [Mentor Name]."). Higher scores indicated higher levels of psychosocial, career, or role-modeling support from a given mentor.

Relationship satisfaction Relationship satisfaction was measured with one item from the Mentor Satisfaction scale (historical internal consistency $\alpha = 0.90$; (Ensher & Murphy, 1997). Participants responded to the statement "I am satisfied with my relationship with [Mentor Name]" on a scale from 1 (not at all) to 7 (to a large extent). Higher values indicated stronger relationship satisfaction with their mentors.

Relationship duration and contact frequency Participants indicated how long they had known each mentor in years (relationship duration) and how many hours per week they spent with their mentors (contact frequency).

Network structures Network level descriptors (e.g., size, density, proportion of women) were calculated to describe structures or patterns of each participant's developmental mentor network. The effective size of one's network represents the number of unique, non-redundant, or unconnected mentors in their network and is on a continuous scale of 1.0 to 5.0 (Perry et al., 2018). The density of connections among mentors within one's network represents the proportion of observed ties among mentors compared to the total possible ties among mentors (Perry et al., 2018). Density was calculated only for those who had two or more mentors ($n = 230$). Density scores range from 0 to 1, with higher density scores meaning more mentors in the network are connected to one another.

For each student's mentor network, several proportion indicators were calculated to represent the composition of their network (e.g., gender, race/ethnicity, career status). For example, the proportion of women mentors was calculated by dividing the number of women mentors in a student's network by the total number of mentors in their network (reference group = proportion of men). This same process was done for the proportion of men, Hispanic/Latino(a) and White mentors, as well as the proportion of faculty mentors, post-baccalaureate, undergraduate, and mentors outside the university.

Plan of analysis

All continuous variables were transformed into Proportion of Maximum Percentage (POMP) scores to adjust all scores on a standard metric of 0–100% (Cohen et al., 1999). Continuous and categorical predictors were group-mean centered within mentor networks (Level-1) and were aggregated and grand-mean centered between students (Level-2) for multilevel analyses (Enders & Tofighi, 2007). In addition, two cross-level interaction variables were created between the Level-2 and Level-1 demographic variables to indicate whether participants shared the same gender and ethnicity/race as their mentors.

A series of multilevel linear models (i.e., mentors nested within students) were implemented to test the impact of mentor characteristics, mentee characteristics, and similarities on mentor support and relationship satisfaction across the network, controlling for factors such as university, major, contact frequency, and relationship duration (Fig. 4) in Stata version 17.0 (StataCorp, 2021). Importantly, the multi-level modeling approach simultaneously captures both dyadic (Level-1) and network average (Level-2) impacts on the mentoring relationships. Model implied variance explained (R2) was calculated using the Stata package "mlmeval" (Gambino et al., 2022; Rights & Sterba, 2019). Furthermore, a series of multiple regression models were implemented to test the impacts of mentee characteristics on the structure of mentor networks (i.e., density, effective size, composition), controlling for the factors described above. Given the pre-registered nature of the hypotheses, we utilized a confirmatory approach to model testing, which allows for estimating variance explained within a single model rather than using a model-building approach (Raudenbush & Bryk, 2002; Rights & Sterba, 2019). To control for Type 1 error rate, we utilized the Benjamini–Hochberg false discovery rate controlling procedure (Benjamini & Hochberg, 1995). Only significant parameters from the Benjamini–Hochberg procedures will be interpreted (full results can be seen in Additional file 1: Tables S2 and S3). Standardized values were calculated using Stata's "estadd" package, which follows Hox and colleagues' approach to standardization (Hox et al., 2017; Additional file 1: Tables S2 and S3).

Results

Preliminary analyses

Preliminary analyses of the Spring 2021 undergraduate responders ($N = 935$) showed that 44% of White students ($n = 188$) and 42% of Hispanic/Latino(a) students ($n = 214$) identified having at least one mentor ($\chi^2 = 0.66$, $p = 0.42$; see Additional file 1: Tables S1 Note). This indicates that, amongst those in our sample, there were no

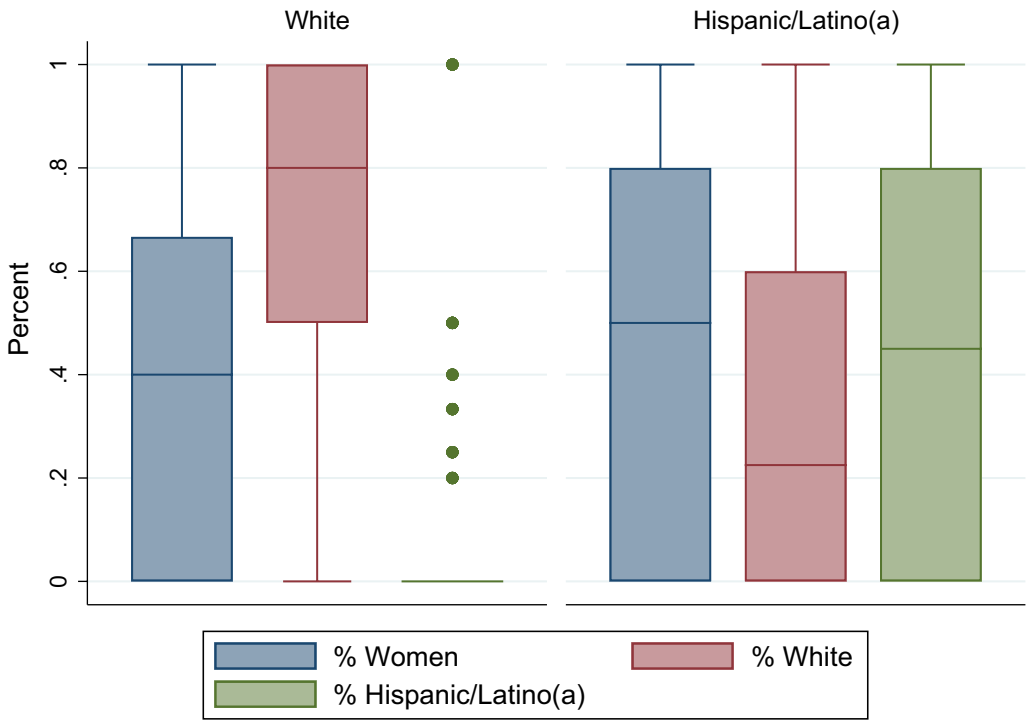

Fig. 2 Boxplot of network structures (gender and ethnicity/race) by White and Hispanic/Latino(a) students

differences in having at least one mentor based on their ethnicity. However, it is important to note the significant gap in students being able to identify having a mentor, regardless of ethnicity (further discussed below).

Characteristics of undergraduates' mentor networks

We examine network descriptive statistics to address our first research question. Among participants with at least one mentor, Hispanic/Latino(a) and White participants had similarly sized networks of mentors (see Table 1 and Table 1 note). By contrast, the composition of student networks differed such that compared to White students, Hispanic/Latino(a) students had a higher composition of Hispanic/Latino(a) mentors, a lower composition of White mentors, slightly higher proportions of women in their networks (Table 1, Fig. 2). Regarding network composition of mentor roles, Hispanic/Latino(a) and White students had similar proportions of mentors from outside the university. In contrast, Hispanic/Latino(a) students had slightly higher proportions of faculty members in their networks (Fig. 3).

Bivariate correlations within student mentor networks (Table 2) and between students (Table 3) showed that the characteristics of mentors and the characteristics of students and their networks in aggregate sometimes differentially related to support. For example, students perceived receiving slightly more psychosocial and role modeling support from the Hispanic/Latino(a) (vs. White) mentors within their networks (Table 2), but in aggregate, students with higher proportions of Hispanic/Latino(a) mentors reported overall lower levels of career support (Table 3). By contrast, students perceived receiving higher levels of psychosocial, career, and role modeling support from mentors with whom they shared similar outlook, perspective, and values (psychological similarity) within their networks (Table 2), and in aggregate, students with higher overall levels of mentor–mentee psychological similarity reported higher overall levels of support (Table 3).

Characteristics of students and their mentors that influence support and satisfaction

To address questions 2–4, we first conducted a series of multilevel models predicting the content and strength of support (i.e., supports and relational satisfaction) from student and mentor characteristics (e.g., mentee gender, mentor gender), as well as similarities (e.g., demographic similarity), controlling for mentoring correlates (e.g., contact frequency) and background variables (e.g., college rank).

Psychosocial support

As depicted in Fig. 4, the multilevel regression model (mentors within students) explained a

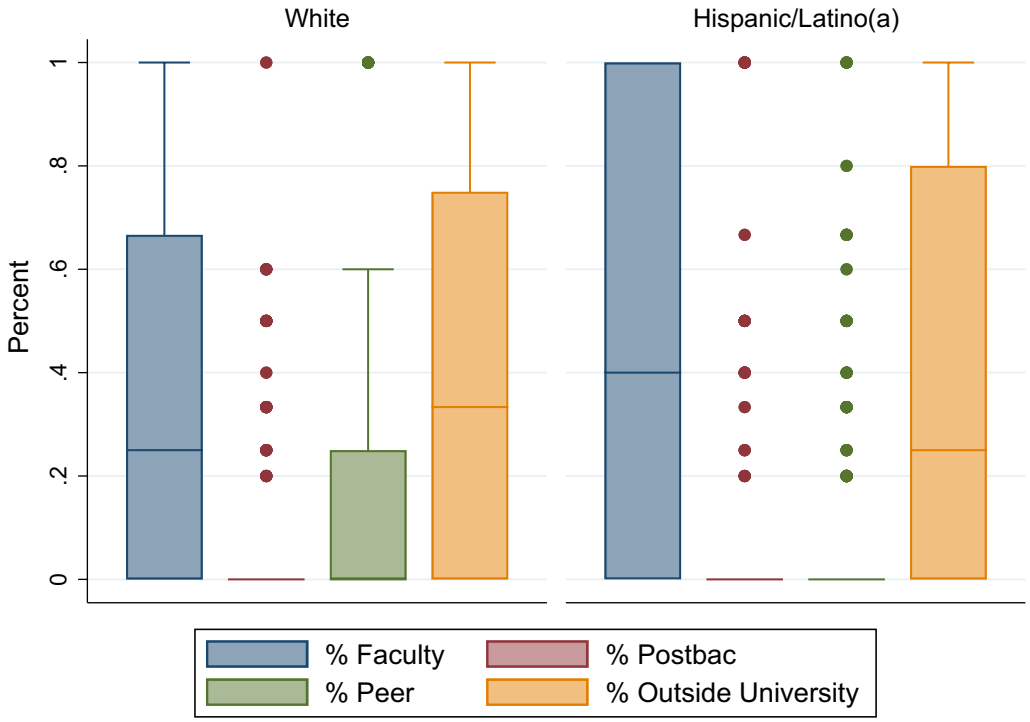

Fig. 3 Boxplot of network structures (role) by White and Hispanic/Latino(a) students

small-to-moderate proportion of within-student variability ($R^2 = 0.12$) and a large proportion of between-student variability ($R^2 = 0.60$) in psychosocial support (Additional file 1: Table S2 for full details). Concerning mentor characteristics, the results indicated that students reported receiving more psychosocial support from mentors within their network who they perceived as more psychologically similar to themselves (γ_{80}; Fig. 4; H-1a partially supported). No other mentor characteristics predicted psychosocial support. Concerning mentee characteristics, students with higher network average mentor–mentee psychological similarity reported higher average psychosocial support (γ_{035}; Fig. 4; H-1b partially supported). No other mentee characteristics predicted average psychosocial support.

Finally, we assessed the impact of demographic similarity on psychosocial support by, as an example, estimating a cross-level interaction of mentee gender on the mentor gender. The cross-level interaction was non-significant, indicating that the level of psychosocial support received from men mentors (vs. women) was unchanged for gender-similar or -heterogeneous pairings. Similarly, there was no evidence of a racial/ethnic similarity impact on psychosocial support.

Career support

The multilevel regression model explained a small proportion of within-student variability and a large proportion of between-student variability in career support (Fig. 4 and Additional file 1: Table S2 for full details). Concerning mentor characteristics, the pattern was the same as above. Students reported receiving more career support from mentors within their network whom they perceived as more psychologically similar to themselves (γ_{80}; Fig. 4; H-1a partially supported). Concerning mentee characteristics, again, students with higher network average mentor–mentee psychological similarity reported higher average psychosocial support (γ_{035}; Fig. 4 H-1b partially supported). However, students with higher proportions of Hispanic/Latino(a) mentors reported receiving lower career support (γ_{028}; Fig. 4), which was unexpected. No other student characteristics predicted average career support. Finally, neither gender nor racial/ethnic mentor–mentee similarity influenced the level of support.

Role modeling support

The multilevel regression model explained a large proportion of within-student variability and a large proportion of between-student variability in role modeling

Table 2 Summary of correlations and descriptive statistics among variables within student networks (Observations = 822)

Variable	1	2	3	4	5	6	7	8	9
1. Psychosocial Support	–								
2. Career Support	.17***	–							
3. Role Modeling Support	.21***	.27***	–						
4. Relationship Satisfaction	.38***	.25***	.39***	–					
5. Psychological Similarity	.38***	.20***	.48***	.50***	–				
6. Mentor Man[b]	− .16***	.07*	− .04	− .11**	− .07*	–			
7. Mentor Other Gender[b]	.03	.11**	.03	.05	.04	− .07*	–		
8. Mentor Hispanic/Latino(a)[c]	.11**	.02	.15***	.17***	.16***	.01	.0001	–	
9. Mentor Other Race[c]	− .04	− .07	− .07*	− .07	− .03	− .002	.05	− .38***	–
10. Mentor Postbac[d]	.04	− .04	.02	− .02	.05	− .04	− .06	.05	− .002
11. Mentor Undergraduate[d]	.14***	.07	.19***	.16***	.21***	.04	.15***	.10**	.06
12. Mentor Outside the University[d]	.03	− .004	.06	.04	.02*	.001	− .02	.16***	− .14***
13. Relationship Duration (Years)	.17***	− .03	.20***	.18***	.18***	− .03	− .02	.27***	− .21***
14. Contact Frequency (Hours per week)	.17***	.12***	.14***	.16***	.22***	− .05	− .01	.17***	− .09**
Ma	0	0	0	0	0	− .01	− .001	.001	− .001
SD	12.32	12.80	.15	10.89	12.40	.38	.05	.31	.30
Skew	− 1.24	− .80	− .44	− .25	− .38	− .01	4.46	.20	.68
Kurtosis	8.39	7.124	4.93	6.89	5.94	2.34	188.5	3.87	4.12

Variable	10	11	12	13	14
10. Mentor Postbac[ae]	–				
11. Mentor Undergraduate[ae]	− .11***	–			
12. Mentor Outside the University[ae]	− .30***	− .37***	–		
13. Relationship Duration[a]	− .04	− .03	.41***	–	
14. Contact Frequency[a]	.002	.15***	.20***	.33***	–
M[a]	.003	.002	− .001	0	0
SD	.19	.25	.33	22.57	20.91
Skew	1.33	.94	.12	.06	.54
Kurtosis	9.49	5.64	3.24	3.97	5.39

[a] All variables are group-mean centered

[b] Reference group is Woman

[c] Reference group is White

[d] Reference group is Faculty

* $p \leq .05$, ** $p < .01$, *** $p < .001$

support (Fig. 4 and Additional file 1: Table S2 for full details). Concerning mentor characteristics, a similar pattern emerged such that students reported receiving more role modeling support from mentors within their networks who they perceived as more psychologically similar to themselves (γ_{80}; Fig. 4; H-1a partially supported). No other mentor characteristics predicted role modeling support. Concerning mentee characteristics, as above, students with higher network average mentor–mentee psychological similarity reported higher average psychosocial support (γ_{035}; Fig. 4, H-1b partially supported). However, students with higher proportions of undergraduate mentors in their networks perceived significantly lower levels of role modeling support (γ_{031}; Fig. 4), which was not expected. No other mentee characteristics predicted average role modeling support. Finally, neither gender nor racial/ethnic mentor–mentee similarity influenced the level of support.

Relationship satisfaction

Our final multilevel model predicted relationship satisfaction from mentor and mentee characteristics, similarities, as well as psychosocial, career, and role modeling support. The multilevel regression model explained a large proportion of within-student variability and a large proportion of between-student variability in role modeling support (Fig. 4 and Additional file 1: Table S2 for full details). Concerning mentor

Table 3 Summary of correlations and descriptive statistics among variables between students ($N = 322$)

Variable	1	2	3	4	5	6	7	8	9
1. Avg. Psychosocial Support	–								
2. Avg. Career Support	.27***	–							
3. Avg. Role Modeling Support	.35***	.32***	–						
4. Avg. Relationship Satisfaction	.52***	.37***	.33***	–					
5. Avg. Psychological Similarity	.47***	.25***	.52***	.49***	–				
6. Mentee Hispanic/Latino(a) Status[a]	.05**	.01	.06	.08	.04	–			
7. Mentee Man Status[b]	− .17***	− .01	− .03	.07	− .03	− .07	–		
8. Mentee Other Gender Status[b]	.04	− .03	.01	− .08	.01	− .003	− .07	–	
9. Mentee First Gen. Status[c]	.08*	− .03	− .03	.08	.05	.47***	− .03	− .08	–
10. Avg. Relationship Duration	.16***	− .09	.13**	.23***	.19***	− .15**	.16***	− .04	− .04
11. Avg. Contact Frequency	.16***	.06	.25***	.19***	.25***	.003	.08	− .07	.04
12. Proportion Mentor Man[b]	− .17***	.07	− .08	− .02	− .11*	− .07	.29***	− .11*	.02
13. Proportion Mentor Other Gender[b]	− .10***	− .10	− .04	− .11*	− .05	− .08	− .01	− .01	− .08
14. Proportion Mentor Hispanic/Latino(a)[a]	.02	− .18***	.07	.06	.17***	.46***	− .03	− .01	.26***
15. Proportion Mentor Other Race[a]	.05	.08	.002	.06	− .04	.06	− .05	− .05	.06
16. Proportion Mentor Postbac[d]	− .03	.06	.03	.05	.05	.01	.07	− .03	.09
17. Proportion Mentor Undergraduate[d]	.01	− .03	− .07	.03	.10	− .10	− .05	− .04	− .02
18. Proportion Mentor Outside the University[d]	.02	− .12*	.17***	.13*	.15**	− .02	.14*	− .03	− .07
19. Density[e]	.12	− .11	.08	.16*	.09	− .09	.04	− .06	.04
20. Effective Size	.02	.12*	.05	.0002	.08	.07	− .01	.03	− .05
M	6.20	6.17	5.53	6.28	5.87	.52	.46	.01	.49
SD	.96	1.14	1.34	.86	1.06	.50	.50	.08	.50
Skew	− 1.56	− 2.05	− 1.02	− 1.54	− .94	− .07	.14	12.57	.02
Kurtosis	5.65	8.01	4.03	5.89	4.08	1.01	1.02	159.01	1.00

Variable	10	11	12	13	14	15	16	17	18	19	20
10. Avg. Relationship Duration	–										
11. Avg. Contact Frequency	.53***	–									
12. Proportion Mentor Woman[b]	− .01	− .05	–								
13. Proportion Mentor Other Gender[b]	− .04	− .04	.001	–							
14. Proportion Mentor Hispanic/Latino(a)[a]	.18***	.14**	− .06	− .06	–						
15. Proportion Mentor Other Race[a]	− .27***	− .13*	− .07	− .01	− .29***	–					
16. Proportion Mentor Postbac[d]	.06	.08	.02	− .03	.02	.04	–				
17. Proportion Mentor Undergraduate[d]	− .02	.08	− .08	.06	.03	− .06	− .12*	–			
18. Proportion Mentor Outside the University[d]	.48***	.36***	.003	− .06	.12*	− .11*	− .19***	− .29***	–		
19. Density[e]	.09	.11	.09	.04	− .01	− .01	.01	− .05	− .001	–	
20. Effective Size	.05	.02	− .09	.03	.07	.05	.05	.11	.05	− .76***	–
M	3.98	8.88	.45	.004	.29	.67	.07	.13	.39	.53	1.82
SD	2.73	9.08	.38	.07	.37	.30	.19	.26	.40	.39	1.02
Skew	.76	1.49	.20	14.86	.89	− .11	3.21	2.16	.45	.002	1.06
Kurtosis	2.61	4.53	1.66	221.80	2.28	1.42	13.61	6.89	1.65	1.48	3.18

[a] Reference group is White

[b] Reference group is Men

[c] Reference group is students with at least one parent with a Bachelor's degree

[d] Reference group is Faculty

[e] Sample size only includes those with at least 2 mentors ($n = 230$)

* $p \leq .05$, ** $p < .01$, *** $p < .001$

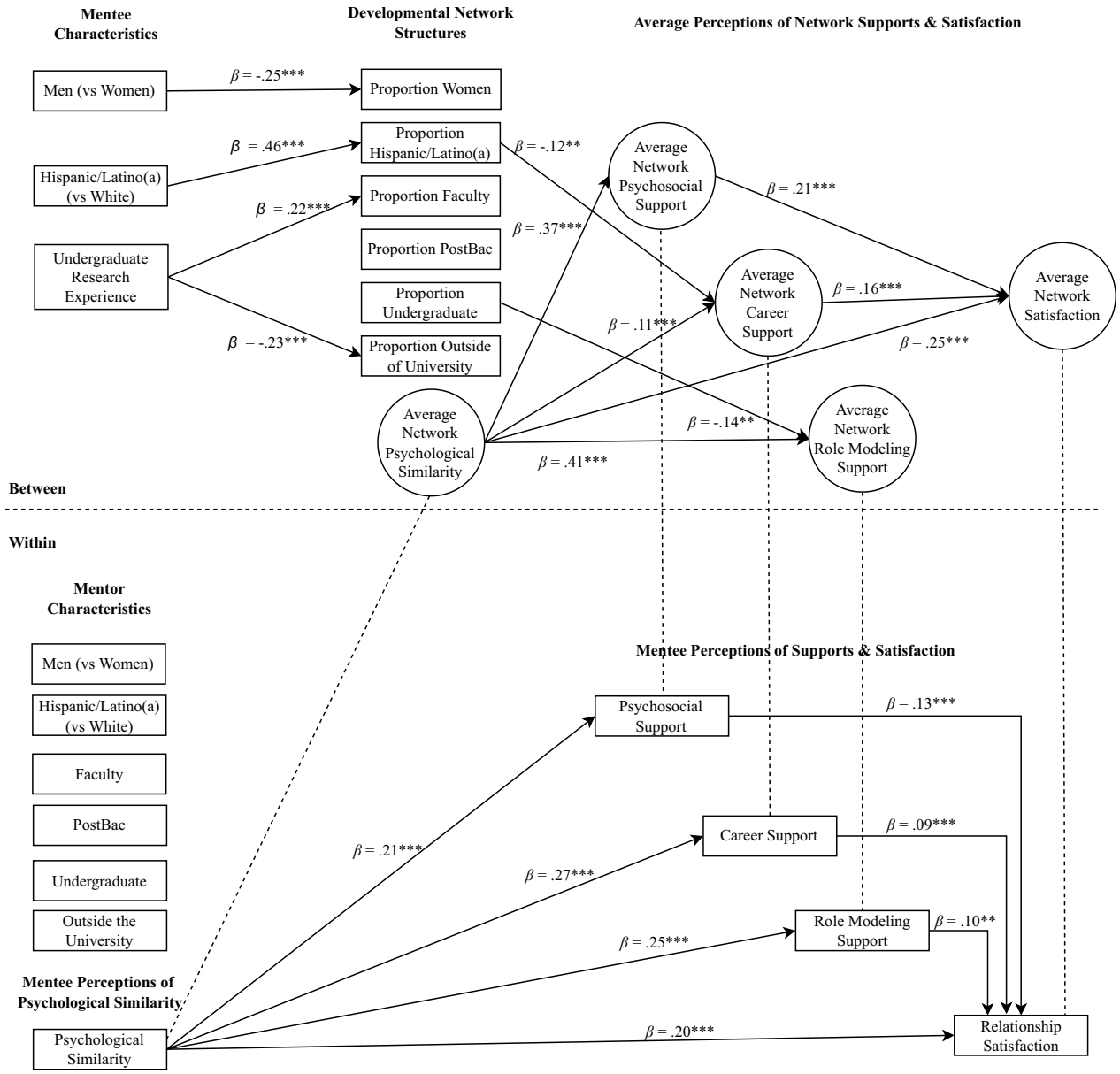

Fig. 4 Path analysis of multilevel model and single level models predicting developmental network structures and content from mentee characteristics, mentor–mentee similarities, and mentoring correlates**.** Rectangles represent measured variables. Circles/ellipses represent network average latent/random effect variables. Dashed lines represent links between within-person variables and between-person network average representations of those same variables. Solid lines represent regression paths that were statistically significant. Beta (β) coefficients represent standardized regression coefficients. *$p < .05$, **$p < .01$, ***$p < .001$

characteristics, consistent with expectations, students reported being more satisfied with mentors within their networks who provided higher levels of role modeling, psychosocial, or career support (γ_{11}, γ_{90}, γ_{10}, respectively), as well as mentors whom they perceived as more psychologically similar to themselves (γ_{80}; Fig. 4; H-1c partially supported). No other mentor characteristics predicted relationship satisfaction. Concerning mentee characteristics, students with higher network average mentor–mentee psychological similarity, psychosocial support, or career support reported higher average mentoring relationship satisfaction (H-1c partially supported). No other mentee characteristics predicted average relationship satisfaction. Finally, neither gender nor racial/ethnic mentor–mentee similarity influenced the level of satisfaction.

Characteristics of students that influence mentor network structures

To address question 2 with regard to network structures, a series of linear regressions were computed to assess the extent to which mentee characteristics predicted network structures, controlling for network average mentoring correlates (e.g., average relationship duration across mentors) and background variables. First, we predicted the network's *effective size* from the set of mentee characteristics and control variables. The results showed that although the overall model explained a statistically significant and moderate proportion ($R^2 = 0.10$) of between-student variability in effective size, none of the mentee characteristics uniquely predicted network effective size (Additional file 1: Table S3; H-2 not supported). Second and third, nearly identical patterns were found for predicting network *density* and for predicting the network composition variable *proportion of peer mentors* (Additional file 1: Table S3; H-2 not supported).

Fourth, we predicted the *proportion of women mentors* from mentee characteristics and control variables. The results model explained a large amount of variability in the *proportion of women mentors* and that women had higher proportions of women mentors within their networks compared to men (Additional file 1: Table S3). Fifth, the model for the *proportion of Hispanic/Latino(a) mentors* revealed that Hispanic/Latino(a) students had higher proportions of Hispanic/Latino(a) mentors in their networks compared to White students, as well as that higher network average relationship duration (i.e., longer relationships) was associated with higher proportions of Hispanic/Latino(a) mentors. Sixth, the model for the *proportion of faculty mentors* revealed that participation in an undergraduate research experience was associated with higher proportions of faculty mentors in their networks, while longer-term relationship durations and higher average contact frequency were associated with lower proportions of faculty mentors. Last, having a higher *proportion of mentors outside the university* was associated with higher average relationship duration and *not* having engaged in an undergraduate research experience.

Discussion

A growing body of research has shown that faculty mentoring improves motivation and persistence among undergraduates pursuing STEM degrees and careers (Estrada et al., 2018a; Schwartz et al., 2018), but less attention has been paid to networks of mentors and the conditions and contexts that promote high-quality networks of support (NASEM, 2019). Therefore, the current study aimed to describe mentor networks and test theory-guided factors that may influence the kind and strength of support, as well as structures of mentor networks in a large and diverse sample of White and Hispanic/Latino(a) undergraduates in STEM. We tested the impact of mentor characteristics, mentee characteristics, and mentor–mentee similarities theorized by the POMM and DNT frameworks, controlling for mentoring correlates and potentially confounding background factors (Eby et al., 2013; Higgins & Kram, 2001; NASEM, 2019).

In our sample, most students reported that they did not have a mentor, but among those that did have a mentor—most reported having two or more mentors. White and Hispanic/Latino(a) students in our sample reported having mentors at a similar rate, and the size of their mentor networks were similarly large. Given that Hispanic/Latino(a) students in the sample were more likely to be first-generation students than their White peers, this finding deviates from other studies that suggest first-generation students were less able to identify a supportive mentor (Garringer & Benning, 2023; Raposa & Hurd, 2021). With the growing body of literature pointing to the positive impacts of supportive mentorship for undergraduate STEM students, universities should continue to implement research-based strategies that promote the development of mentoring relationships (Estrada et al., 2018a; Garringer & Benning, 2023; NASEM, 2019).

Mentee and mentor characteristics that influence support and relationship quality

Across a series of multilevel models, psychological similarity proved to be the most consistent and positive predictor of *all* types of support, as well as relationship satisfaction. This finding is consistent with expectations from POMM and DNT frameworks and in line with prior research in faculty–student mentoring (Eby et al., 2013; Hernandez et al., 2017, 2023a; Higgins & Kram, 2001; Pedersen et al., 2022). Importantly, these findings extend our understanding of the importance of psychological similarity beyond dyadic faculty mentoring relationships to a broader network of mentors who span social arenas. That is, students reported receiving higher levels of support and more relational satisfaction from all kinds of mentors (not just faculty) within their networks with whom they were more similar in terms of outlook and values. Moreover, students who had higher average levels of psychological similarity (across their network of mentors) reported higher average levels of support and relational satisfaction.

Taken together with the knowledge that mentoring support and satisfaction are linked to motivation and persistence in STEM fields—particularly students from under-represented groups (NASEM, 2019), this finding holds promising implications for individual mentors and mentoring program stakeholders. Psychological

similarity is *malleable*, and therefore, may be a good target for interventions aimed at diversifying STEM. Recent research indicates that interventions and practices can help mentors and mentees discover shared similarities in outlooks, perspectives, and values (Du et al., 2023; Hernandez et al., 2023a). For example, perceptions of psychological similarity can be boosted through the "Creating Birds of a Feather" protocol, in which students and teachers complete a brief "getting to know you" survey to learn of shared experiences and preferences (Du et al., 2023; Gehlbach et al., 2016; Robinson et al., 2019). Furthermore, robust quasi-experimental evidence indicates that brief structured biographical interviews, such as the Entering Research curriculum (Branchaw et al., 2020a, 2020b), can boost mentee's perceptions of psychological similarity with their research mentors (Hernandez et al., 2023a). Promoting psychological similarity is particularly important as it provides a way for mentoring programs to lessen the burden of identifying demographically similar mentors for students, particularly given that women faculty and faculty of color are significantly under-represented in the STEM fields (Campos et al., 2021; Casad et al., 2021).

Contrary to POMM and DNT-based expectations, the characteristics of individual mentors (e.g., their gender, race, or professional role) within student networks had no impact on support or relational satisfaction. Previous studies showed students with women faculty mentors reported higher levels of perceived psychosocial and career support than those with mentors who were men (Kuchynka et al., 2023). Our results differ, in part, because we were asking students to report on multiple mentors within their networks rather than making comparisons between students with women and men as primary mentors. Furthermore, when aggregated to a between-student characteristic, students with a higher proportion of men mentors (relative to women) in their networks reported lower levels of psychosocial support—although the proportion was not uniquely predictive. These results expand the scope of mentorship beyond primary faculty mentors to include a wide range of mentorship, thus capturing a more nuanced view of mentoring supports.

In addition (and counter to POMM and DNT-based expectations), we found that mentor–mentee gender- and racial/ethnic similarity had no impact on satisfaction. While this may contradict expectations and some empirical evidence pointing to the positive role mentor–mentee gender- and racial/ethnic similarities can play in mentor support and satisfaction (Blake-Beard et al., 2011; Morales et al., 2018), others have echoed our results of negligible associations (Hernandez et al., 2017, 2023a). Taken together with information on the importance of psychological similarity, we interpret the lack of impact due to individual mentor demographics or demographic similarity as an opportunity for mentoring stakeholders supporting diverse students in STEM. Mentors and mentoring programs may wish to expend their limited resources amplifying mentor–mentee shared psychological and experiential similarities.

The pattern of results linking mentee characteristics, as well as network average mentor characteristics, with support and satisfaction were nuanced. Generally, mentee characteristics such as race/ethnicity and gender were unrelated to mentorship support or quality. However, network average mentor characteristics exhibited small-to-moderate associations with network average mentorship support. The most consistent finding was that students with higher average perceptions of similarity with their mentors reported receiving higher levels of all kinds of support and relationship satisfaction. This finding was consistent with mentoring theories and prior research on primary mentors (Eby et al., 2013).

Two less consistent patterns based on the compositional qualities of student networks were also observed. Students with higher proportions of undergraduate mentors reported lower levels of network average role modeling support. This finding implies that peer mentor networks may provide supports other than those associated with inspiration from identifying with the life and accomplishments of a near-peer. In addition, we found that students with higher proportions of Hispanic/Latino(a) mentors reported receiving less career support. In the context of this study, having Hispanic/Latino(a) mentors was highly positively related to having longer relationships and increased contact, as well as being from outside of the university. By contrast, there were higher percentages of White faculty mentors than Hispanic/Latino(a) faculty mentors. The implications of these findings are threefold. First, these findings are reflective of systemic inequities within higher education—that is, inequities leading to under-representation of faculty from diverse racial/ethnic groups (NCSES, 2023). Second, these findings suggest that those with larger Hispanic/Latino(a) mentor networks bring with them long-lasting mentoring relationships that can convey strengths through consistency and affirmation of cultural values and identity (Estrada et al., 2018b, 2022). Third, universities and higher-education stakeholders should endeavor to rectify systemic inequities to create opportunities for students to expand their social capital on campus. This is consistent with prior social network studies that suggest the importance of social capital, particularly for first-generation and lower socioeconomic-status students, in spaces where there is an alignment of one's goals for the future (Aikens et al., 2016; Joshi et al., 2019; Lukács

& Dávid, 2023; Martin et al., 2014; Schwartz et al., 2018). This mirrors findings in the mentoring literature where researchers encourage students to engage in extracurricular academic activities, research, and internships that provide access to mentors who integrate students in the STEM field (Keller & Lindwall, 2020; NASEM, 2019; Raposa & Hurd, 2021; Thiem & Dasgupta, 2022). Importantly, researchers urge universities to find ways to lessen the burden of these engagements for under-represented students and socioeconomically disadvantaged students, such as providing college credit for engaging in these experiences.

The overall quality of mentoring relationships is of interest, as relationship quality is theoretically and empirically the strongest mentoring process associated with downstream outcomes (Eby et al., 2013). Our results indicate that, as expected, *all* types of support from mentors within a student's network (as well as psychological similarity) predicted relational satisfaction. Furthermore, students with higher network average levels of psychosocial and career support (as well as psychological similarity) also reported higher network average relational satisfaction. These findings extend and are highly consistent with prior research conducted with mentoring dyads and faculty mentors (Eby et al., 2013). Furthermore, this finding is consistent with prior work showing that the quality of mentoring support can be boosted through interventions that promote high-quality relationships within a student's network (Du et al., 2023; Hernandez et al., 2023a).

Influencers of mentor network structures

Regarding mentor network structures, contrary to expectations, there were no differences between student demographic characteristics in determining the effective size or density of one's mentor networks. There were, however, demographic similarities within mentor networks, wherein women tended to have larger numbers of women in their networks compared to men, and Hispanic/Latino(a) students, compared to their White counterparts, tended to have larger proportions of Hispanic/Latino(a) mentors in their networks (sometimes called homophily effects). This finding is supported by the literature wherein students from historically underrepresented backgrounds may benefit from having mentors who are demographically like them (Morales et al., 2018; Pedersen et al., 2022; Thiem & Dasgupta, 2022). However, given the number of women and historically under-represented ethnic groups in many STEM fields decreases going up the rank in academia (i.e., graduate students, postdocs, faculty; Casad et al., 2021), access to demographically similar mentors may pose challenging for many students, imploring stakeholders to implement research-based strategies to support historically underrepresented groups at all ranks of careers (Campos et al., 2021; Thiem & Dasgupta, 2022).

This work extends the literature on undergraduate STEM mentoring by highlighting the variations in mentoring support afforded by a myriad of mentors, rather than just faculty mentors, and the important role of promoting psychological similarity across a broad network of mentors. Institutions should utilize programs that promote skills to acquire mentorship, expand social capital, and promote high-quality mentoring relationships (e.g., Connected Scholars, Entering Research; Branchaw et al., 2020a, 2020b; Schwartz et al., 2018) and provide students with guidance on how to not only find one mentor but expand their network with multiple developmental mentoring relationships.

Limitations and future work

While the current study addresses a gap in developmental mentor network studies of STEM undergraduates, several limitations that hinder the generalizability and provide opportunities for future research of complementary approaches to enhance and tease out findings. First, mentoring data were collected during the Spring of 2021, approximately one year into the COVID-19 pandemic. While research on the long-term impacts of social support due to the pandemic is still developing, recent works point to a decline in student performance and well-being (Bonacini et al., 2023). However, another study identified that higher levels of satisfaction with mentoring relationships were associated with lower levels of well-being, pointing to the potential positive impacts of mentoring relationships to buffer the negative consequences of the pandemic (Saw et al., 2022). Future work should continue to assess the long-term impact of the COVID-19 Pandemic on students and their mentoring relationships. The current sample consists of undergraduate students who are either White (non-Hispanic) or Hispanic/Latino(a) (of any race), most of whom are in their senior year of undergraduate tenure. Future studies should examine if similar patterns found in this study exist amongst students of varying ethnic demographics, including intersectional identities (e.g., Burt et al., 2020), amongst students in earlier stages of their undergraduate programs and would benefit from varied approaches (e.g., open-ended interviews), and the degree to which implicit biases by influence perceptions of psychological similarity. It is also important to note that the traditional sex categories the authors used during data collection may limit the scope of understanding. Although the initial intention was to capture gender identity rather than biological sex, future work should more closely examine and align with gender identities.

In addition, there are several limitations of this network study that lend a direction for future expansion of work. First, mentor network measures were only captured at one time point. Given developmental networks are dynamic, future work could assess the extent to which the composition of a student's developmental network might shift and the downstream impact of these mentoring relationships on motivational outcomes (e.g., GPA, STEM identity). In addition, the phrasing of the name interpreter question as a "professional relationship" might have limited the variety of students' mentor network nominations. Future work could broaden the scope of inclusion criteria for network nomination to further characterize students' developmental mentor networks. Importantly, future work should also identify the various ways in which STEM students are obtaining specific mentors. While we did not explicitly investigate multiplexity, future work could also address if and how certain mentors in a network provide multiple types of support in order to further address the quality of mentoring relationships compared to simply increasing the size of one's network. Moreover, the study design used ego-centric network analysis, limiting the number of questions asked to participants for each mentor nominated to reduce the response burden. Although only a single item was asked for each mentoring process and satisfaction and thus does not allow for a latent approach to the measurement of these variables, this tradeoff was necessary when comparing the burden that would have been on respondents with the overwhelming number of items for each nomination. Finally, the current study specifically addressed the positive aspects of mentoring relationships. Per the recommendation of NASEM, future research should inquire about the negative aspects of mentorship and its impact on developmental network formation, student success, and integration into STEM fields (Eby et al., 2013; NASEM, 2019; Robnett et al., 2019).

Conclusions

The main objectives of this study were to examine how contextual factors, informed by the Process-Oriented Model of Mentoring (POMM) and Developmental Network Theory (DNT), are associated with characteristics of students' mentor networks, as well as the qualities of mentorship support across a diverse set of mentors for undergraduate STEM students. Among students who reported having a mentor(s), the size of mentor networks did not differ between White and Hispanic/Latino(a) students. While there was evidence of homophily in some aspects of network structures, wherein women had more women mentors and Hispanic/Latino(a) students had more Hispanic/Latino(a) mentors, there was overwhelming evidence for the importance of and opportunity in psychological similarity in promoting supportive mentoring relationships. The findings of this study not only contribute to theoretical understanding of developmental mentor networks for undergraduate STEM students but directly inform how programs and universities might support the development of diverse mentor networks to positively influence academic success and retention.

Abbreviations

STEM	Science, technology, engineering, and mathematics
HU	Historically under-represented
NCSES	National Center for Science and Engineering Statistics
NASEM	National Academies of Sciences Engineering and Medicine
POMM	Process-oriented model of mentoring
DNT	Developmental network theory
IRB	Institutional review board
POMP	Proportion of maximum percentage
GPA	Grade point average

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40594-024-00480-9.

Additional file 1: Table S1. Summary of descriptive statistics for the proportion of undergraduates with an identified mentor compared to total undergraduate who took the Spring 2021 survey (n=935). **Table S2.** Summary of parameter estimates from multilevel models predicting content of mentorship support and relationship satisfaction using Benjamini–Hochberg corrections for Type-I error rate inflation (n = 322, Observations = 822). **Table S3.** Summary of parameter estimates from linear regressions predicting mentor network structures (n = 322).

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Author contributions

RP contributed to the conception of the research questions, acquisition, analysis, and interpretation of the data and was a major contributor in writing the manuscript. AW and PWS contributed to the acquisition of the data, were contributors in editing the manuscript, and are PIs on the project. PRH contributed to the conception of the research questions, acquisition, analysis, and interpretation of the data, was a major contributor in writing the manuscript, and is a Co-I on the project. All authors read and approved the final manuscript.

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Availability of data and materials

The data sets used and/or analyzed during the current study will be made freely available from the Texas Data Repository, https://doi.org/https://doi.org/10.18738/T8/TWC1AJ. Pre-registered research questions and hypotheses are available on OSF: https://doi.org/https://doi.org/10.17605/OSF.IO/F2RV8.

Declarations

Competing interests

The authors declare that they have no competing interests.

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