

RESEARCH ARTICLE

Operationalizing and monitoring student support in undergraduate engineering education

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Abstract

Background: Supporting undergraduate students in science, technology, engineering, and mathematics (STEM) has been a persistent need. However, assessing the impact of support efforts can prove challenging as it is difficult to operationalize student support and subsequently monitor the combined impacts of the various supports to which students have access simultaneously.

Purpose/Hypothesis: This paper describes the development of the STEM student perspectives of support instrument (STEM-SPSI) and explores how perceptions of student support constructs vary across engineering students.

Design/Method: Following best practices for instrument development, forming the STEM-SPSI consisted of an iterative cycle of feedback from various STEM stakeholders and two rounds of pilot testing with students at multiple institutions. We employed factor analysis to identify student-support constructs and conduct validation procedures on the instrument.

Results: Results suggest that student support can be conceptualized as a combination of 12 constructs. The STEM-SPSI can help engineering educators evaluate their student-support mechanisms at an academic-unit level.

Conclusions: The practical contribution of the STEM-SPSI is to assist colleges in monitoring the extent to which their portfolio of support mechanisms is perceived as helpful by undergraduate students. This work makes a theoretical contribution to the model of cocurricular support that undergirds the instrument by producing empirical evidence for its constructs.

KEYWORDS

assessment, evaluation, instrument development, student support, survey research

1 | INTRODUCTION

Institutions and academic units invest considerable resources to support undergraduate students, both inside and outside of class (Wang, 2013). We refer to the collective intended benefits of these resources as “student support.” Holistic student support is essential for: (a) students pursuing degrees in STEM (science, technology, engineering, and

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mathematics), where undergraduate programs have been pressured to increase enrollments while facing retention problems (Linley & George-Jackson, 2013) and (b) students who face systemically linked, oppressive barriers within the educational system because of their identities (i.e., marginalized students; Wang, 2013). This study is motivated by the need to better support students who live at the intersection of these two populations (i.e., marginalized students in STEM). In the context of engineering, various subpopulations are marginalized because of factors such as their race, class, or gender (e.g., Black students, low-income students, or women). Being marginalized means facing unique barriers in STEM and educational inequity compared with students from more dominant groups (Dickerson et al., 2014; Lee & Cross, 2013; Linley & George-Jackson, 2013; Z. S. Wilson et al., 2012).

Throughout this paper, we consider STEM as a whole as well as engineering and science separately (where science is used to refer to nonengineering STEM disciplines, or STM). Although foundational knowledge bases and many barriers and supports cut across the entire STEM field (Belser et al., 2017; Espinosa, 2011; Flower, 2014; Gayles & Ampaw, 2014; Museus et al., 2011; Ong et al., 2018), we are cognizant of differences between engineering and science (e.g., one is a professional field) as well as organizational structure differences (e.g., most institutions delineate a school/college of engineering, whereas science disciplines can be grouped as its own unit or in combination with a range of “arts” disciplines).

At the institution level, senior leadership teams often designate entire offices and administrative roles to champion support efforts, where employees are explicitly responsible for supporting underrepresented students across academic colleges (e.g., University of Iowa’s, 2008 Center for Diversity and Enrichment). However, the complex and persistent challenges to improve diversity and increase the quantity of bachelor’s degrees awarded in STEM, particularly in engineering, have resulted in student-support initiatives carried out at the academic-unit level (i.e., college- or discipline-specific initiatives). The use of discipline-specific initiatives is particularly common in colleges of engineering at large, predominantly White institutions (PWIs) (i.e., institutions with a full-time equivalent enrollment of at least 10,000 students and in which White students account for 50% or greater of the student enrollment), where minority engineering programs (MEPs) and women in engineering programs (WEPs) have been commonplace for decades (Flores & Della Piana, 2000; Lee & Matusovich, 2016). Other common structures consist of more isolated STEM intervention programs, such as living-learning communities and mentoring programs (M. K. Brown et al., 2009; Piper & Krehbiel, 2015; Z. S. Wilson et al., 2012).

Because support is offered at so many levels of the university/college ecosystem, it is difficult to know if students—especially marginalized students in the contexts of large PWIs—feel supported and to what extent. Our work addresses the need to better understand the impact of student-support efforts in STEM learning environments with large undergraduate enrollments. In these settings, it is challenging to get a pulse on students’ experiences because interpersonal approaches (e.g., one-on-one conversations) become less feasible as educators and administrators are responsible for more students, and a survey instrument designed to measure student support in the context of undergraduate STEM education is yet to be developed. Although many existing instruments can be used to measure a variety of constructs that often serve as proxies for student support (A. R. Brown et al., 2005; Heller et al., 2010; Litzler & Young, 2012), none, to our knowledge, have been developed explicitly focused on STEM student-support efforts.

1.1 | Purpose and contributions

The purpose of this paper is to explore how to operationalize and measure student support in STEM—considering which supports transcend engineering and science boundaries and which supports are unique to the engineering context. The traditional approach to monitoring student support is to evaluate the impact of individual interventions (Newton et al., 2001; Samuelson et al., 2014; Single et al., 2005); however, in this paper, we flip this logic. Rather than focusing on specific offices or interventions, we focus on the STEM learning environment more holistically. As an analogy, just as the body derives nutrients from a variety of food sources, students receive support from a variety of support efforts. Our approach focuses on measuring the key nutrients that make up student support so that institutions may identify areas in need of greater support.

We describe the development and testing of an instrument that can be used to measure undergraduate STEM students’ perceptions of support across a portfolio of a college’s support efforts. Our analysis highlights key distinctions between engineering and science such that modified versions of the instrument can be considered for different organizational contexts. This instrument is theoretically grounded in the model of cocurricular support (MCCS), which indicates how students’ interactions with the academic, social, and professional systems in a college and the broader university system can influence their success in an undergraduate degree program (Lee & Matusovich, 2016). The following research questions guided our instrument development:

1. What factors emerge when operationalizing the student-support constructs as outlined in Lee and Matusovich's (2016) model of cocurricular support?
2. How does the resulting instrument and its latent constructs meet standards for instrument validation?

Because of the current lack of clarity regarding the underlying elements that make up student support in STEM, our research addresses a fundamental gap in the research on student support—what it means to support students and how support efforts can be monitored. The constructs of student support are empirically grounded in the experiences of undergraduate students and observed by administrators (not excluding faculty) from colleges of engineering and sciences at PWIs. As we note, because experiences and needs differ across science and engineering disciplines as well as across individual departments, we expected differences between how support operates across academic units. Our goal was to capture such anticipated variation to build further evidence of validity.

In developing and testing the STEM-SPSI, we oversampled students from underrepresented groups to ensure their voices were captured in the development process and included multiple academic units (i.e., engineering and sciences departments) to ensure the instrument is sensitive enough to note disciplinary differences. For example, when comparing engineering and science programs, there are typically differences in demographic composition (e.g., women make up larger percentages of students enrolled in and graduating from science programs) as well career pathways (i.e., the baccalaureate degree serves as the first professional degree for most engineering disciplines, whereas most sciences degrees require graduate education; Lichtenstein et al., 2010; Millett, 2003). Incorporating diverse perspectives and students from both engineering and science programs in the development process was crucial to reveal nuances in measurements that could function differently across local STEM contexts.

2 | LITERATURE REVIEW

Current options for assessing student support in STEM typically have two key characteristics: (1) reliance on germane psychological constructs as proxies of support (e.g., student engagement, campus climate, sense of belonging, student integration; Allen, 1999; Dickerson et al., 2014; Hedrick et al., 2010; Johnson, 2012; Lee & Cross, 2013; Rainey et al., 2018; D. Wilson et al., 2015) or (2) using instruments designed for institution-level evaluation of students' experiences and perceptions to evaluate college-level support interventions (e.g., Cooperative Institutional Research Program, Revealing Institutional Strengths and Challenges). Although these measures can provide high-level insight, we argue that an instrument specifically measuring STEM student support would be more effective for two reasons. First, the reliance on germane psychological constructs as proxies results in feedback that is often too abstract to inform practice. Second, instruments designed to address institution-level efforts are seldom applicable for evaluating support interventions at the academic-unit level.

2.1 | Proxy measures of student support

For higher education institutions in the United States, "student support" is a colloquial term resulting in educators and researchers alike using various psychological constructs to understand the underlying phenomena. For instance, student engagement, belonging, and campus climate are all commonly used to provide high-level perspectives of STEM (Hedrick et al., 2010) and higher education learning environments (Hausmann et al., 2007; Kahu, 2013; Kane et al., 2014; Kuh, 2001; Stebleton et al., 2010; Velasquez, 1999).

Some of the common factors assessed with these instruments include faculty and staff practices, quality of interpersonal relationships, organizational functions, and safety (Dymnicki et al., 2013; Holahan & Batey, 2019) as well as active and collaborative learning, level of academic challenge, enriching educational experiences, student–faculty interaction, and supportive campus environments (Pascarella et al., 2010). Such data are useful for individual office accountability and for assessing student engagement and climate at an institution level as well as identifying needs for institutional improvements. However, findings from these instruments can be limiting when the purpose of the measurement is to bolster support at the academic-unit level because the feedback is aimed at the quality and source(s) of support (e.g., career center) an institution offers and does not necessarily reflect useful feedback for the types and quality of support that academic-level programs aim to provide (e.g., professional networking opportunities).

Similar to student engagement and climate, sense of belonging is another common proxy for evaluating support in STEM (Johnson, 2012; Rainey et al., 2018; D. Wilson et al., 2015). However, sense of belonging is highly contextualized,

having social, academic, and institutional components. Thus, existing measures of belonging vary in focus, illustrated by the social belonging measure developed by Hoffman et al. (2002), the sense of academic fit used by Walton and Cohen (2007), and pride in belonging to an institution used by Freeman et al. (2007). These varied measures of belonging yield mixed results when evaluating students' sense of belonging and the connection it has to student outcomes.

Consider that a college of engineering has multiple support initiatives aimed at enriching educational experiences. The feedback from an instrument measuring student engagement could provide metrics for student participation, satisfaction, and exposure to programs intended to enrich educational experiences. However, if student engagement is found to be low at the college level, from a practitioner's standpoint, it would be difficult to discern whether there need to be more opportunities for engagement or, rather, program offerings that students find more engaging.

2.2 | Institution-level assessments

In addition to the common use of psychological constructs, previous researchers also have developed more practice-oriented instruments to better understand undergraduate students and the prevalence of desired educational practices. For example, the Cooperative Institutional Research Program (CIRP) is a widely used survey instrument for first-year students (Eagan et al., 2014; Higher Education Research Institute, 2020; Keup, 2004; Pryor et al., 2010) that aids in understanding students' perceptions of learning and their development (Keup, 2004). The instrument provides a snapshot of students' expectations of college, their values, goals, academic preparedness, demographic characteristics, established behaviors from high school, and concerns about financing higher education (Eagan et al., 2014; Pryor et al., 2010). Instruments like CIRP can help plan for incoming cohorts and are especially useful for informing institutions of what services are needed or expected by students.

Similar to CIRP, some more recently developed survey instruments allow for institutional customization, facilitating ease of use and specificity for individual universities and their needs. For example, the Revealing Institutional Strengths and Challenges (RISC) instrument (Porter & Umbach, 2018) facilitates an institution-level assessment of over 80 specific challenges to student success across five areas: (1) finances and financial aid, (2) academic support services, (3) campus environment, (4) success in courses, and (5) work and personal life. The RISC instrument also captures student experiences with specific campus offices and is well suited to evaluate services the university provides in terms of student satisfaction and frequency of use across services. However, such high-level assessments are not sensitive enough to evaluate the efficacy of targeted student-support efforts implemented at lower organizational levels (i.e., academic units or sub-units) that aim to reach a relatively small population of marginalized students.

We argue that an instrument focused on the quality and type of support, rather than the quantity and specific source of support, will provide different useful information to educators and administrators seeking to improve the suite of support offerings holistically.

3 | THEORETICAL FOUNDATION

We ground the instrument theoretically using the model of cocurricular support (MCCS), which repurposes Tinto's model of institutional departure (Tinto, 1993) for colleges of engineering. While Tinto's model explains how students' interactions with academic and social systems influence student retention at an institutional level, the MCCS explains how students' interactions with academic, social, and professional systems influence student success in an undergraduate engineering program. We selected the MCCS as a theoretical framework because it focuses on students' experiences at the academic-unit level (e.g., college of engineering) and aligns with our purpose while enabling us to connect our findings to the larger body of literature using Tinto's model.

3.1 | Tinto's model of institutional departure

Tinto's model (1993) is a well-known theoretical framework used in educational research (Longwell-Grice & Longwell-Grice, 2008; Nora et al., 1990; Towles & Spencer, 1993) to study the persistence and retention of marginalized students, especially in engineering and STEM programs (French et al., 2005; Ulriksen et al., 2015; Walden & Foor, 2008). Before Tinto's contribution to the literature, student departure was primarily viewed independently of the

learning environment. External factors, along with an individual's actions, were the determinants of student success and were considered to be beyond the control of an institution (Lee et al., 2018; Summerskill, 1962; Tinto, 1993). Tinto's model, in contrast, focuses on student interactions during college to identify the social and academic factors that contribute to a student's decision to leave an institution (Tinto, 1993). The central construct of Tinto's model is student integration: it asserts that students will choose to withdraw if they are not able to establish full membership within an academic community (Tinto, 1993).

The wide and varied use of Tinto's model has yielded several critiques (Lee et al., 2018; Longwell-Grice & Longwell-Grice, 2008). Two critiques relate to diversity: (1) the model lacks sufficient consideration for students who are marginalized culturally, racially and/or ethnically; and (2) the model only applies to traditional students attending institutions in a residential setting. In reference to critique 1, the central tenet of Tinto's model (i.e., student integration) ignores the reality that some students encounter a different culture from their own when attending college and may never become fully integrated with their institution. As a consequence of the central tenet, Tierney (1992) asserts that assuming integration could be particularly harmful to Black and brown students who have to adopt the culture of Eurocentric PWIs. Rather than emphasizing cultural assimilation, student integration should focus on students' perceptions of integration as a result of institutional support (Hall, Verdín, Lee, Godwin, et al., 2019). In reference to critique 2, some scholars question the applicability of the model and its constructs for examining integration and withdrawal of nontraditional students, particularly part-time and commuter students (Ashar & Skenes, 1993; Bean & Metzner, 1985). The work of Bean and Metzner (1985) suggests that nontraditional students attend college primarily for academic purposes and, therefore, do not socially integrate into an institution. This hypothesis suggests that nontraditional students develop different social connections to the university and alludes to a more complex relationship between social integration and persistence in commuter students (Pascarella et al., 1983). Mixed findings from prior research (e.g., Borglum & Kubala, 2000; D'Amico et al., 2014) suggest that support differs across student groups and further supports our position that not all student-support constructs will present similarly across all student groups. Our instrument addresses this nuance by breaking student support down into subcomponents; it was intentionally developed to be sensitive to the needs of STEM student groups typically marginalized at PWIs.

There are three additional critiques of Tinto's model, which have been raised related to measurement: (3) the model treats social and academic integration as mutually exclusive (Beekhoven et al., 2002), which does not account for the complexity of student integration factors (French & Oakes, 2004; Hall, Verdín, Lee, Godwin, et al., 2019; Kamphorst et al., 2015); (4) studies measure academic and social integration constructs inconsistently (e.g., D'Amico et al., 2014; Marra et al., 2015; Nora et al., 1990; Wolf-Wendel et al., 2009; Woosley & Shepler, 2011); and (5) frequent use of one-dimensional measures (i.e., use of one or two item scales) for integration constructs raises validity concerns (e.g., Ashar & Skenes, 1993; Cabrera et al., 1992; D'Amico et al., 2014).

In addition to these five critiques, we add that Tinto's model focuses entirely on student retention as situated at the institution level. However, STEM student-support practices are often implemented at the academic-unit level. This potential misalignment between student-retention theory and student-support practice may leave decision makers with abstract ideas for interventions meant to foster student integration (e.g., transition, incorporation, and full participation) and no instrument with which to evaluate their effectiveness at the academic-unit level. Taken together, these critiques of Tinto's model are relevant for understanding why we used the model of cocurricular support—a framework adapted from Tinto's model to be applicable to engineering. Our analysis considers its applicability across STEM contexts more broadly.

3.2 | Lee and Matusovich's model of cocurricular support

The model of cocurricular support identifies support systems that influence the academic success of engineering students (Lee, 2015; Lee & Matusovich, 2016). The MCCS suggests that it is necessary to consider the academic, social, and professional (i.e., discipline-specific career path) systems within a college (e.g., college of engineering) as well as the institutional context in which the college is embedded (Lee, 2015; Lee & Matusovich, 2016).

Systematically conceptualizing the learning environment using the MCCS serves as a foundation for understanding how to build institutional capacity to support undergraduate students in engineering. According to the MCCS, the essential elements of institutional support stem from the experiences enabled by interventions—metaphorically, the

TABLE 1 Six essential areas defining the model of cocurricular support's theoretically hypothesized factor structure

Academic support	Institutional support geared toward disseminating information related to improving academic performance or circumstances, providing access to resources that support academic performance, monitoring academic performance or development, or contributing to the development of content-independent and content-dependent skills that contribute to academic performance
Faculty-interaction support	Institutional support geared toward disseminating information related to interacting with faculty/staff, increasing the number of interactions students have with faculty/staff, and helping students establish relationships with faculty or staff
Extracurricular support	Institutional support geared toward disseminating information related to improving or increasing extracurricular involvement and providing students with opportunities
Peer-interaction support	Institutional support geared toward disseminating information related to students interacting with other students, increasing the number of interactions that students have with other students outside of the classroom, or grouping students based on some part of their identity or academic circumstances
Professional development support	Institutional support geared toward developing industry-independent skills that contribute to obtaining employment; disseminating information related to career opportunities via an undergraduate degree in STEM; providing work experiences that contribute to the professional development of students via employment; providing access to role models along different career trajectories; or developing industry-independent skills that contribute to successful professional performance
Additional support	Institutional support geared toward acclimating students into the university environment; facilitating access to financial assistance; publicly acknowledging the success of students; or discussing life as an underrepresented student in STEM

MCCS identifies the nutrients (i.e., support) that students receive from the food (i.e., interventions; Lee, 2015; Lee & Matusovich, 2016). The benefit of studying student support with this approach is that these elements provide a way to deconstruct student interventions and identify the underlying experiences being facilitated. Although specific interventions may not be transferable (or implemented identically) across contexts, this deconstruction reveals students' experiences that can transcend contexts within and across institutions.

To develop the MCCS, Lee and Matusovich (2016) conducted a four-institution study examining the engineering support interventions offered by six different offices. The perspectives of student-support practitioners and students were paramount in deconstructing each intervention to identify its underlying contribution to student support. Tinto's model provided a foundation to define undergraduate engineering student experiences; six essential areas defined in Table 1 emerged as essential to student support in engineering (Lee & Matusovich, 2016). This paper further operationalizes these six student-support constructs via a new instrument, which will also enable empirical justification for grounding student-support practices on the MCCS and consider its usefulness in operationalizing student support in STEM more broadly.

4 | RESEARCH TEAM POSITIONALITY

Our team's identities influenced our methodological choices and processes (Secules et al., 2021). First, our instrument development process was influenced by our research interest and lived experiences in STEM education. All five authors' primary research interest is in engineering education, each focusing on issues related to marginalization and student support. And each of the five authors earned an undergraduate degree in STEM, four of which were in engineering and one in science. This combination of interest and experiences resulted in the inclusion of STEM disciplines broadly with a prioritization of engineering students. Second, our social identities influenced how we related to the students we were studying and what we noticed in their responses. Two of the authors are Black (one Black man and one multiracial woman), two of the authors are White (one White man and one White woman), and one author is a Latina. Lastly, our expertise and previous experiences in engineering education influenced which tradeoffs we made as it relates to research quality and practical applicability. Across all members of the team, we have experience with both research and practice as it relates to student support. Thus, in addition to focusing on research quality, we made decisions that would increase the usability of the instrument from the perspective of practitioners.

5 | INSTRUMENT DEVELOPMENT

We employed an iterative cycle of feedback during instrument development from a number of stakeholders in STEM. Qualitative data collection included individual interviews with students, focus groups with both undergraduate and graduate students, and written feedback from administrators within STEM colleges. Quantitative data were collected from two rounds of pilot surveys followed by factor analysis to scrutinize newly developed items and whether items adequately measured the MCCS constructs. As noted previously, given that colleges of science and engineering both face challenges to support and retain marginalized students, we included science students in piloting the MCCS-based instrument. We expected to see some differences in how science and engineering students perceive support; observing such differences between colleges of engineering and science contribute evidence of the instrument's validity as well as potential contextual expansion of the MCCS.

In this work, we frame validity as a unifying concept consistent with the *Standards for Educational and Psychological Testing* (American Educational Research Association [AERA] et al., 2014). Validity is defined as:

the degree to which evidence and theory support the interpretations of test scores entailed by proposed uses of tests. Validity is, therefore, the most fundamental consideration in developing and evaluating tests. The process of validation involves accumulating evidence to provide a sound scientific basis for the proposed score interpretations. It is the interpretations of test scores for proposed uses that are evaluated, not the test itself. (AERA et al., 2014, p. 11)

Thus, we describe a validation process of gathering evidence to support an argument for the use of the STEM-SPSI to measure diverse students' perceptions of support across STEM contexts. These sources of evidence provide ways to consider different aspects of validity, but they do not represent distinct types of validity. We describe the process of evidence gathering and testing in the sections that follow.

5.1 | Instrument 1.0 prototype development

We followed the instrument development process described by DeVellis (2011) and Gall et al. (2007), beginning by ensuring items adequately covered the entire scope of the MCCS constructs. We re-analyzed data that generated the constructs for the MCCS (i.e., open-ended student interviews about cocurricular support) and converted students' responses into closed-ended statements about cocurricular support. The closed-ended statements served as an initial item bank that aligned with the theoretically hypothesized six essential areas of the MCCS (refer to Table 1). Using an iterative process, we also reviewed germane existing survey instruments (refer to Table 2) to determine which, if any, aspects of the undergraduate experience were not yet captured in the closed-ended statements and added additional items where necessary to develop the instrument prototype.

The instrument prototype was evaluated to ensure clarity, comprehension, acceptability of the questions, and survey length using several rounds of stakeholder feedback. In total, 46 stakeholders (38 students and 8 administrators) provided suggestions and recommendations for revising the prototype (refer to Table 3 for a summary). We conducted focus groups and cognitive interviews with students to understand if the set of items were worded clearly and applied

TABLE 2 List of surveys informing student-support prototype development

Education & Training (E&T) Evaluation Form (Matheis & Sue, 2011)
Human Relation Facilitation (HRF) Process Interview, Intake & Demographics (Matheis & Sue, 2017)
College of Engineering Report (Virginia Tech, 2017)
Engineering Majors Survey (National Center for Engineering Pathways to Innovation, 2017)
Project to Assess Climate in Engineering (PACE) Survey (CERSE, University of Washington, 2012)
Professional Engineering Pathways Study (PEPS) Survey (Professional Engineering Pathways Research Team, 2016)
University of Washington Pre-testing Protocol, Version 9 (University of Washington, 2007)
University of Washington Center for Workforce Development PEERS Survey Instrument (Mody-Pan, 2013)

TABLE 3 Timeline of qualitative feedback and quantitative analysis informing survey development process for instrument prototype

Semester	Goal	Method	Participant information
Fall 2017	Survey applicability, identify missing experiences and support	Four focus groups	Undergraduates ($n = 16$): 4 students from University 1 and 12 from University 2; 14 engineering and 2 science students; 11 women and 5 men
Fall 2017	Item-by-item feedback, check for face validity	Interviews	Undergraduates ($n = 8$): 3 students from University 1 and 5 from University 2; 6 engineering and 2 science students; 6 women and 2 men, 2 sophomores, 2 juniors, 3 seniors, and 1 sixth year
Fall 2017	Time to completion, interpretation of items, and relevance of response options	Survey review	Graduate engineering education researchers ($n = 14$): 8 women, 5 men, and 1 genderqueer or non-binary transgender; 4 Black/African American, 1 Mexican, 1 Hispanic or Latino, 1 East Asian, 6 White, and 1 declined to answer
Fall 2017	Appropriateness, survey format, and length	Feedback forms	STEM administrators ($n = 5$): administrators across five institutions completed feedback forms; advisory board ($n = 3$): engineering education researchers with expertise in survey development and diversity, equity, and inclusion
Spring 2018	Instrument Pilot Test 1.0	Electronic deployment	Undergraduate STEM students, 3 institutions ($n = 973$)
Summer 2018	Exploratory factor analysis using ($n = 722$; Hall, Verdín, Lee, Knight, et al., 2019)		
Fall 2018	Survey iteration	Survey review	Same STEM administrators ($n = 5$); same advisory board ($n = 3$)
Fall 2018	Survey applicability and item-by-item feedback	Interviews	Undergraduates ($n = 8$): students from University 2; 5 engineering and 3 science students; 6 women, 2 men, 4 sophomores, 2 juniors, 2 seniors
Spring 2019	Instrument Test 2.0	Electronic deployment	Undergraduate STEM students, 9 institutions ($n = 865$)
Summer 2019	Confirmatory factor analysis using ($n = 865$)		
Fall 2019	Additional invariance testing and validation ($n = 865$)		

to their lives as well as to solicit feedback on areas of support not included. Administrators and engineering education researchers also provided feedback on survey structure and content. As the purpose of the project was to identify institutional support as it pertains to marginalized populations, we intentionally oversampled marginalized populations based on gender identity and race/ethnicity as well as transfer students. The revisions to the instrument prototype resulted in Instrument 1.0, which included 94 student-support items and 25 items pertaining to student demographics and involvement for a total of 119 items.

5.2 | Instrument 1.0 pilot test

To gather validity evidence for the STEM-SPSI, we administered Instrument 1.0 electronically during Spring 2018 to undergraduate students enrolled in STEM disciplines at three public, research-intensive, land-grant, PWI universities. This context is particularly useful for exploring the experiences of STEM students from underrepresented and underserved groups because it is in these contexts where such students are particularly marginalized. A total of 973 students responded in Spring 2018 to Instrument 1.0. The self-reported demographics of the sample are reported in Table 4. The subsequent exploratory factor analysis was run on 722 of the 973 responses because of missingness in the data.

5.3 | Instrument 1.0 data analysis

We conducted an exploratory factor analysis (EFA) to understand the emergent factor structure of the newly developed instrument. This analytic step provides validity evidence that the items hypothesized to measure a theoretical construct

actually do appear to measure that construct. We used an exploratory approach because this work is emergent and this pilot was the first test of these items to measure the hypothesized constructs.

We first examined the data for items that severely violated normality assumptions by calculating the skew and kurtosis of each item. Next, we examined the correlation among items hypothesized to measure the same latent construct. We took this approach to remove any items that did not significantly correlate with other items in the data (Field et al., 2012; Gorsuch, 1983). Finally, we conducted a Kaiser–Meyer–Olkin (KMO) test for sampling adequacy (Kaiser, 1970). This statistic represents the ratio of the squared correlation among variables to the squared partial correlation among variables using a range from 0 to 1. A value of 0 indicates that there is significant diffusion in the patterns of correlations, and factor analysis may be inappropriate, whereas a value closer to 1 indicates that the patterns of correlations are relatively compact, and factor analysis should yield reliable results. The average KMO for version 1.0 pilot was 0.95.

Once the assumptions of the data for EFA were checked, we used the stats package in R with a maximum likelihood estimate with a promax rotation (R Core Team, 2018). This rotation is oblique and allows for intercorrelation among common factors and allows for a more realistic representation of the related nature of the constructs (Fabrigar et al., 1999). Parallel analysis and a scree plot indicated 13 factors. We extracted this number of factors and removed any items that did not meet the factor loading cutoff of 0.32 (indicating 10% of overlapping variance) or cross-loaded onto multiple factors (as indicated by a secondary loading greater than one-half of the main loading; Tabachnick & Fidell, 2001). A key consideration in factor analysis is evidence that the items that measure a single construct are closely related, and discriminant validity is evidence that factors are distinct and separable from one another in measurement. Both of these considerations are aspects of construct validity, which EFA provides evidence toward. We examined the

TABLE 4 Instrument pilot respondent demographics

Demographic categories^a	Instrument 1.0 Spring 2018 (n = 973)	(%)	Instrument 2.0 Spring 2019 (n = 865)	(%)
<i>Race/ethnicity</i>				
American Indian/Alaskan Native	9	0.92	8	0.92
Native Hawaiian/Pacific Islander	9	0.92	7	0.81
Black/African American	32	3.29	44	5.09
Latino/-a/-x/ or Hispanic	40	4.11	69	7.98
South Asian	33	3.39	37	4.28
East Asian	63	6.47	110	12.72
Southeast Asian	24	2.47	40	4.62
Middle Eastern/North African	16	1.64	20	2.31
White	534	53.85	620	71.68
Another race/ethnicity not listed	11	1.13	9	1.04
<i>Gender identity</i>				
Women	414	57.30	446	51.56
Men	283	39.20	375	43.35
Genderqueer/non-binary	7	0.97	15	1.73
Gender not listed	14	1.94	4	0.46
Prefer not to answer	11	1.52	17	1.97
<i>Additional demographics</i>				
First-year college student directly from high school	638	65.57	742	85.78
First-year college student not directly from high school	4	0.41	19	2.19
Transfer students—Community college	51	5.24	75	8.67
Transfer students—Different 4-year institution	12	1.23	24	2.77
Other	5	0.51	5	0.58

^aParticipants were instructed to mark all that apply for their race/ethnicity, and some students chose not to provide their demographic information.

commonalities of the items (acceptable range of 0.4–0.7; Costello & Osborne, 2005) and removed any items out of this range to ensure that the items structure robustly measured the underlying factors.

During the EFA, we noted differences among responses from science and engineering students' perceptions of support. In particular, engineering students' responses indicated a distinction among support efforts geared at peer interactions. For example, engineering students distinguished support efforts that involved socializing with peers (e.g., "I regularly socialized with STEM students outside of class") from those focused on peer collaboration, particularly outside of their major or STEM (e.g., "I was able to collaborate (academically) with STEM students outside of my major")—science students responded to these items similarly. Additionally, engineering students perceived support efforts for professional development differently. Engineering students distinguished STEM career development from interventions geared at engaging with professionals, and science students did not (Hall, Verdín, Lee, Godwin, et al., 2019; Hall, Verdín, Lee, Knight, et al., 2019). Such differences would be expected since engineering is a professional degree program. As the instrument indicated potential differences among groups, we split the data for these items by engineering and science and examined the factor structure independently. The results indicated a set of items that measured similar constructs for both engineering and science students, with the engineering students responding to the items in a two-factor structure and the science students responding to the items in a one-factor structure. As such, we kept all items that measured these constructs across groups for further testing in the subsequent round.

5.4 | Revising for Instrument 2.0 prototype

The EFA results included a set of 54 items measuring 13 factors. These 13 factors were theoretically consistent with the original set of six theoretically hypothesized MCCS factor structures; instead of six overarching factors, the 13 factors were more specific subareas of the original six theoretical constructs. We developed additional items, as needed, to either make the measurement of each construct more complete or provide a sufficient pool of items to measure the construct reliably. We targeted at least five items per construct to balance the length of the survey while also allowing the potential for some newly developed items to be removed in the next round of piloting. In total, we added 35 items across nine factors.

According to the process outlined in Table 3, we sought qualitative feedback in several rounds with stakeholders (i.e., undergraduate STEM students, institutional partners, and advisory board members). During this process, undergraduate students identified some of the newly added items as not relevant to their experiences, which resulted in item removal from the instrument. Undergraduate student feedback indicated that connections to graduate students were an additional source of support, which was not yet captured in the instrument. The implications of graduate students as a source of support resulted in the addition of a hypothesized factor structure that brought the final construct number to 14 (i.e., graduate student connections).

The resulting Instrument 2.0 contained a total of 117 items: 92 student-support items across 14 constructs and 25 items pertaining to student demographics and involvement.

5.5 | Instrument 2.0 pilot test

The piloting of Instrument 2.0 was administered electronically during Spring 2019 with undergraduate students enrolled in STEM disciplines at nine public universities and colleges. A total of 865 students passed an attention check item that asked students to mark a single numeric response on an anchored scale item (refer to Table 3). This item enabled us to remove students who may have indiscriminately responded to the survey. The response rate is close to the sample size ratio recommended by Nunnally and Bernstein (1978) of sampling at least 10 times as many participants as items. Our sample size is a ratio of 9.7 participants per item; the KMO was 0.94, indicating an adequate sample size for further analysis.

5.6 | Instrument 2.0 data analysis

With these data, we used confirmatory factor analysis (CFA) to test if the responses measured the 14 hypothesized constructs. We used this statistical technique because the structure of the items was well hypothesized during the revision of Instrument 1.0 and via feedback from stakeholders. CFA provides evidence that the measures of a construct are consistent with the a priori hypothesized structure. To conduct the analysis, we used the lavaan package in R with

maximum likelihood estimation with robust SEs and a Satorra–Bentler scaled test statistic (R Core Team, 2018; Rosseel, 2012). This approach was appropriate as the data met univariate normality assumptions but did not meet multivariate normality assumptions (Chou et al., 1991). A total of 11.4% of the data were missing; we used full-information maximum likelihood to impute the missing data using the Amelia package in R (Honaker et al., 2011).

After estimation, the model was trimmed of low loading items (<0.5) for parsimony and to ensure a common underlying factor measurement (Awang, 2012). We removed 15 items that did not share enough common variance to measure the factors they were hypothesized to measure as indicated by squared factor loadings (shared variance less than 25%). Of these items removed, eight were newly developed items, and 10 were items from the previous pilot. We also combined two pairs of factors that were highly correlated (Pearson's $r > .7$) to improve the discriminant evidence for the measurement: combining the STEM career development factor with the engaging with professionals factor and combining the extracurricular information factor with the developing a local network factor.

Once the model was properly specified, we tested for model fit. Several fit indices were used to evaluate the model based on Byrne's suggestions (2013) including chi-square (should be nonsignificant at the $p < .05$ value; Byrne, 2013), comparative fit index (CFI; acceptable values occur above 0.9; Hu & Bentler, 1995), Tucker–Lewis index (TLI; acceptable values occur above 0.9; Hu & Bentler, 1995), and root mean square error of approximation (RMSEA; values less than 0.01, 0.05, and 0.08 indicate excellent, good, and moderate fit, respectively; MacCallum et al., 1996). The model did not indicate good fit (CFI = 0.874; TLI = 0.867; RMSEA = 0.044 ± 0.002 , 90% confidence interval), so we examined the modification indices and item residuals for ways the model could be re-specified.

The residuals and modification indices indicated that some items within factors should have correlated errors, which indicates that some items related to one another more than with other items within the factor. We examined the items and found that the flagged items were similarly worded or had a closer common meaning than other items within the same factor. For example, we correlated the errors for the item, “I had opportunities to participate in out-of-class activities with other STEM students,” and the item, “I had opportunities to participate in out-of-class activities that fit within my schedule.” This correlated error also is intuitive as these were the two items retained from the developing a local network factor when it was combined with the extracurricular information factor. The 14 factors developed to measure student support are unidimensional but they also probed a wide range of student experiences within each factor. This rationale is consistent with the discussion of possible model misspecification when there is a strong content overlap and the reality that forcing large error terms to be uncorrelated is often inappropriate with sociopsychological data (Bentler & Chou, 1987; Byrne, 2013). We note that these decisions should not be solely based on post hoc model statistics to improve model fit. In three other cases, where this rationale was not readily applied, we deleted the lower loading item to ensure factor unidimensionality.

Additionally, two items had large residuals (>0.1) with a number of other items (including items across multiple different factors): “I received help in setting my academic goals,” “I felt valued as a student at this university,” and “I received helpful guidance on planning how to integrate out-of-class experiences (e.g., internships or spending a semester abroad) with my plans to graduate.” Large residuals indicate that the model does not accurately capture the relationship among these variables and that these items were not uniquely measuring the factor they were intended to measure; therefore, we removed these items.

6 | FINAL INSTRUMENT: STEM STUDENT PERSPECTIVES OF SUPPORT INSTRUMENT (STEM-SPSI)

The final CFA had a total of 70 items across 12 factors. An overview of the final factor categories and an accompanying definition can be found in Table 5.

Figure 1 displays how the final constructs mapped back to the six original theoretically hypothesized MCCA factor structures. As compared with the original MCCA constructs, we measured more specific factors conceptually linked to the original theoretical framework. Appendix A includes an overview of the total number of items, the full set of item loadings, variance extracted, convergent and discriminant validity evidence, the reliability of each factor, and Cronbach's alphas. All of the factors had Cronbach's alphas greater than .8 indicating high internal consistency and that the items may be used interchangeably (Thorndike & Hagen, 1997).

Additionally, all factors had average variance extracted greater than 0.46, which is close to the recommended value of 0.50, and the average variance extracted was greater than the correlation among constructs indicating discriminant

TABLE 5 Twelve factors defining the student perceptions of support instrument based on confirmatory factor analysis

Construct	Definition
Academic advising support	Institutional support geared toward disseminating information related to improving academic performance or circumstances, providing access to resources that support academic performance, or monitoring academic performance or development
Academic peer support	Institutional support geared toward improving or increasing interactions among students that contributed to their academic success
Faculty support	Institutional support geared toward establishing, improving, or increasing interactions among students and faculty/staff as it relates to their academic performance
STEM faculty connections	Institutional support geared toward establishing, improving, or increasing interactions among students and STEM faculty/staff, increasing the quality of interactions students have with faculty/staff, and helping students establish relationships with faculty or staff related to professional development
Student affairs support	Institutional support geared toward helping students navigate nonacademic aspects of the student experience
Out-of-class engagement	Institutional support geared toward improving or increasing extracurricular immersion in both social and professional activities hosted on campus and around the local community
STEM peer connections	Institutional support geared toward interactions among students in STEM majors, increasing the number of interactions that students have with other students outside of the classroom, or grouping students based on some part of their academic circumstances
Graduate student connections	Institutional support geared toward students interacting with graduate students, developing mentoring relationships, or networks to promote learning and professional growth
STEM career development	Institutional support geared toward career opportunities via an undergraduate degree in STEM, providing access to experiences and role models to prepare me for a career in STEM, or developing industry-independent skills that contribute to successful professional performance
General career development	Institutional support geared toward developing industry-independent skills that contribute to obtaining employment or providing access to resources that contribute to the professional development of students along different career trajectories
Cost-of-attendance support and planning	Institutional support geared toward facilitating awareness and access to financial assistance needed to attend the university
Diversity and inclusion	Institutional support geared toward acclimating students into the university environment or promoting diversity and inclusion in the form of resources as well as celebratory events

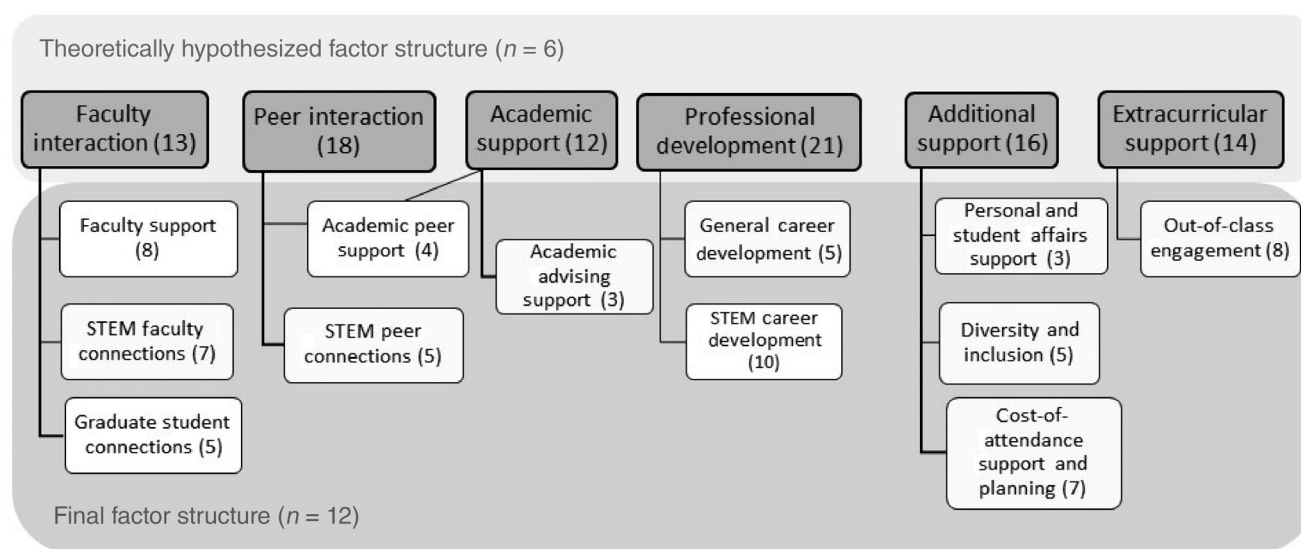


FIGURE 1 Changes in student-support constructs from six essential areas outlined by the MCCS to 12 final constructs after confirmatory factor analysis

TABLE 6 Students' mean responses on support items by self-reported race and gender

Support construct	Women (438)					Men (365)				
	White (275)	Asian (78)	Black (18)	Latinx (32)	Two or more races (35)	White (237)	Asian (58)	Black (13)	Latinx (32)	Two or more races (25)
Faculty support	3.92	3.82	3.67	3.75	3.66	3.88	3.79	3.51	3.47	4.00
STEM faculty connections	2.84	2.49	2.27	2.77	2.35	2.74	2.47	2.29	2.73	3.08
Graduate student connections	2.30	2.31	1.95	2.30	2.09	2.19	2.22	1.90	2.54	2.64
Academic peer support	3.76	3.66	3.26	3.68	3.31	3.74	3.55	3.69	3.25	3.99
STEM peer connections	4.02	3.81	3.32	3.72	3.68	3.96	3.65	3.89	3.66	3.83
Academic advising support	3.89	3.67	3.90	3.73	3.80	3.87	3.89	3.72	3.52	4.09
General career development	2.25	2.38	1.83	2.22	2.11	2.07	2.70	2.33	2.36	2.02
STEM career development	3.44	3.36	2.88	3.56	3.05	3.43	3.17	2.94	3.34	3.49
Personal and student affairs support	3.63	3.42	2.48	3.12	2.96	3.37	2.92	3.00	2.86	3.60
Diversity and inclusion	3.66	3.56	2.78	3.57	3.36	3.60	3.71	3.23	3.40	3.63
Cost-of-attendance support and planning	2.63	2.64	2.99	3.05	2.81	2.94	3.00	3.19	2.41	2.32
Out-of-class engagement	3.77	3.76	3.47	3.63	3.49	3.70	3.73	3.49	3.48	3.89

Note: Sample sizes are reported for each group in parentheses. There are some race/ethnicities not reported due to low sample sizes. Additionally, we asked about students' gender to include non-binary students, but these numbers have not been included here as the risk of reidentification at the intersection of race and gender is high. The highest mean for each support construct is shown in bold and the lowest mean for each support construct is shown in italics.

validity evidence (Fornell & Larcker, 1981). All factors had at least three indicator variables, which ensures that the model is over-identified and the fit statistics can be properly estimated (Raubenheimer, 2004). The fit indices were CFI = 0.913, TLI = 0.908, RMSEA = 0.041 ± 0.002 , 90% confidence interval, indicating good fit of the model with the data. The chi-square ($\chi^2 = 5330.2$, $p < .001$) was statistically significant, but this result is often the case with sample sizes greater than 400 (Schumacker & Lomax, 2004).

The final model (refer to Appendix B) provides a useful way to measure students' experiences and perceptions of support across a web of different support efforts within a college and provides ways to understand how students feel they are supported, regardless of the source of support. All of the constructs in Appendix B are covaried, and the correlations among constructs are shown in Appendix C (maximum correlation of .65).

6.1 | Score comparisons

Our recent preliminary work using the final STEM-SPSI instrument examines student-support differences across engineering and science students (Hall, Verdín, Lee, Godwin, et al., 2019). Preliminary findings demonstrate that the instrument is sensitive enough to detect differences. As an example, we examined the results for support by gender and race/ethnicity from our second round of data as well as by broad discipline (Tables 6 and 7). When

TABLE 7 Students' mean differences on support items by college

Support constructs	Engineering (590)			Science, technology, and mathematics (STM) (273)			<i>t</i> -statistic	Significance ^a	Adjusted <i>p</i> value	Effect size (<i>d</i>)
	Mean	SE	SD	Mean	SE	SD				
Academic advising support	3.88	0.04	0.92	3.73	0.06	1.04	2.02	*	.053	0.09
Academic peer support	3.89	0.04	0.92	3.63	0.06	1.00	5.02	***	.000	0.22
Faculty support	3.81	0.03	0.76	3.92	0.05	0.78	−2.03	*	.053	0.09
STEM faculty connections	2.74	0.04	1.07	2.82	0.07	1.12	−0.94	–	.348	–
Graduate student connections	2.24	0.05	1.19	2.57	0.08	1.33	−3.54	***	.001	0.16
Out-of-class engagement	3.60	0.04	0.89	3.40	0.06	0.93	2.95	**	.006	0.13
STEM peer connections	3.99	0.04	1.01	3.56	0.07	1.08	5.58	***	.000	0.24
Student affairs support	3.46	0.04	1.06	3.32	0.07	1.12	1.76	–	.086	–
STEM career development	3.34	0.04	0.95	2.90	0.06	1.01	6.06	***	.000	0.26
General career development	2.35	0.04	0.96	2.55	0.06	1.07	−2.72	**	.012	0.12
Cost-of-attendance support and planning	2.90	0.04	1.03	2.62	0.06	1.03	3.61	***	.001	0.15
Diversity and inclusion	3.46	0.04	1.02	3.29	0.06	1.02	2.26	*	.037	0.10

Note: Sample sizes are reported for each group in parentheses. The highest significant mean for each support construct is shown in bold.
^aThe level of statistical significance is coded in the absence of adjusted *p* value: * represents a statistical significance less than .05 but greater than or equal to .01, ** represents a statistical significance less than .01 but greater than or equal to .001, and *** represents a statistical significance less than .001.

examining students' perceptions of support at the intersections of race and gender, particular patterns in mean responses emerged. Men who identified with two or more race/ethnicities had higher self-reported averages, compared with all other groups, in terms of receiving faculty support, connecting with faculty and graduate students, academic advising support, out-of-class engagement, and leveraging a supportive network consisting of peers, academic advisors, and student affairs personnel. However, men in the multiracial group predominately identify as both White and Asian (i.e., 71% of that group), and we know from the most recent ASEE report that White and Asian students make up a high proportion of enrollments and earned degrees (American Society for Engineering Education, 2020). Additionally, we know that a large proportion of engineering faculty across ranks are predominately White and Asian men (American Society for Engineering Education, 2018). Dasgupta's (2011) work reminds us of the positive effect ingroup experts and peers have on students' academic fit, and we postulate that such a phenomenon helps explain why students from the engineering "ingroup" are more likely to perceive certain kinds of support. In contrast, Latinx men reported the lowest feelings of support from faculty, in general, STEM peers, academic advising, and out-of-class engagement compared with all other racial/ethnic groups across men and women. Black women reported the lowest feelings of support across connections with graduate students, STEM peer connections, STEM and general career development, personal and student affairs support, and diversity and inclusion. Compared with all the racial/ethnic groups across men and women, Black women showed consistently lower ratings on the support constructs. A dissatisfaction with institutional support at predominately White institutions (i.e., in the form of lower self-reported ratings) is unfortunately not uncommon for Black students (e.g., Eakins & Eakins, 2017; M. L. Russell & Russell, 2015; Winkle-Wagner & McCoy, 2018). Most notably, M. L. Russell and Russell's (2015) study found that Black women switched out of their STEM disciplines because of inadequate career counseling and advisement, and Winkle-Wagner and McCoy (2018) noted that the lack of campus diversity related to Black students' perception that the campus was not a supportive environment. The self-reported responses of Black women corroborate these earlier findings and, most importantly, help identify specific institutional support efforts that need to be improved at PWIs to support Black women's STEM retention. Overall, these findings provide an example of how perceptions of support are differentially experienced by students across the intersections of race and gender, which is exactly what the STEM-SPSI was designed to reveal.

We explored group mean differences of science and engineering students using Welch's *t*-tests. A Welch's *t*-test accounts for populations with unequal variance. Because we ran 12 different *t*-tests, we also corrected for Type I error using a false discovery rate *p*-value correction (Benjamini & Hochberg, 1995). The results from the Welch's *t*-tests in Table 7 show statistically significant differences with small effect sizes (i.e., $0.09 < \text{Cohen's } d < 0.26$). For students in engineering and science, we found differences across the areas of support. Specifically, science students reported stronger connections to graduate students and indicated they received more faculty support. Science students felt stronger support for general career development, including professional schools and graduate school, whereas engineering students felt stronger support for preparation for STEM careers. Considering the professional nature of the engineering baccalaureate degree, it is understandable that an emphasis to prepare and develop professional engineers has had an influence on support offerings (e.g., engineering-focused career fairs). An engineering baccalaureate degree is considered the first professional degree or standard degree for practice in the field, whereas baccalaureate degrees from science programs typically are nonprofessional degrees (J. S. Russell et al., 2000). Understandably, students preparing to enter their field of practice (i.e., engineering students) would perceive support related to STEM career development differently than students who are seeking nonprofessional degrees (i.e., science students). Engineering students indicated a stronger connection with peers, reported receiving more academic advising support, more information on how to participate in out-of-class activities, cost-of-attendance support and planning, and diversity and inclusion efforts. These differences indicate that the instrument can identify variation across STEM fields and indicates particular areas to improve support. It may also indicate differences in the cultural norms and career preparation between science and engineering pathways.

7 | LIMITATIONS

Regarding transferability of instrument findings, the focus of instrument development was for STEM student-support efforts at institutions with high undergraduate enrollments (i.e., large PWIs). Additionally, the MCCS constructs originated from a study of engineering student-support centers. Although the instrument was piloted with students from both colleges of science and colleges of engineering, there could be limitations on the transferability of the instrument to assess STEM student support at different institutional types and in nonengineering programs—that latter point is a key focus area of our analysis. Although additional testing is needed to facilitate greater transferability, the STEM-SPSI can help colleges examine their portfolios to identify the kinds of support that students feel that they do and do not receive.

Concerning the quality of self-reported survey responses, the work by Porter (2013) suggests that students employ a belief-sampling approach when responding to subjective type items on surveys. A belief-sampling approach means that the response process to items on a survey follows retrieval of random considerations—an assortment of feelings, impressions, beliefs, general values, prior judgments, and related memories to the item in question. Respondents then use these considerations to select a response to a given item. Evidence also suggests that the considerations used in a belief-sampling response approach typically relate to a student's educational experiences. These considerations are largely driven by student choices and, thus, related to students' background characteristics. Based on this research, the concerns of self-report instruments are applicable for contexts in which respondents evaluate objective learning gains like conceptual understanding (Porter, 2011) and less so for the items assessing student perceptions of experiences, like the items in our survey.

Given that considerations used to make a judgment are said to be sampled from prior educational experiences, there does exist the potential for students to use prior educational (e.g., K–12) or collegiate experiences (Porter, 2013) when answering our survey items about their perceptions of support at their most current institution. To mitigate this concern and direct attention to current institution-specific experiences, we took considerable efforts in piloting the wording of survey items with undergraduate students. For example, certain items were bound by time and space (e.g., “over the past year at your institution”) or scoped to a source of support (e.g., “My college was committed to ...”). We engaged students and administrators at multiple institutions throughout the development of our survey instrument to ensure it is understandable, transferable, and serviceable across a variety of institutional contexts and student demographics.

8 | DISCUSSION OF FINAL FACTORS

Based on the process outlined in this paper and the strong theoretical basis for these measures, we have developed an instrument with robust validity evidence that measures a wide range of student-support perceptions. Our results

indicate 12 areas of student support, which are internally consistent and important, for considering student experiences in engineering and science. Each of the originally hypothesized areas from the MCCS was largely maintained in this instrument development process. However, based on qualitative feedback and instrument validation processes, we found subfactors within and across each of these areas.

First, faculty interaction from the MCCS largely remained distinct, measured by students' beliefs about *faculty support* for their academic and personal success as well as the frequency and opportunities to interact via *STEM faculty connections* and *graduate student connections*. We included graduate students as a separate factor after our pilot participants highlighted the importance of graduate student mentors in research and as teaching assistants as being separate kinds of relationships than those between undergraduates and faculty.

Second, peer interaction and academic support from the MCCS had a clear intersection. Peer interaction was measured by two factors: *academic peer support* and *STEM peer connections*. Students conceptualized academic peer interactions (e.g., study groups) as different from social interactions and connections. In addition to *academic peer support*, academic support was also measured by the quality of *academic advising support*. This result (i.e., *academic peer support*) highlights an interaction among areas the MCCS presented as more distinct and suggests that these components of the student experience are not always so easily compartmentalized.

Third, professional development and extracurricular support from the MCCS largely remained distinct. Professional development was conceptualized as being different for STEM versus non-STEM career pathways and preparation and operationalized as *general career development* and *STEM career development*. Extracurricular support largely remained the same in our instrument as originally theorized. The focus of this factor, *out-of-class engagement*, was narrowed through the validation process to community and university engagement via student organizations and leadership opportunities.

Lastly, the additional supports component of MCCS is split into *personal and student affairs support*, *diversity and inclusion*, and *cost-of-attendance support and planning*. The personal and student affairs support captured a general sense of support in the on-campus environment and housing. Diversity and inclusion included both receiving formal communications and information about diversity and inclusion topics as well as a general sense of commitment to these values by students' respective colleges. Cost-of-attendance support and planning included both receiving information about financial considerations as well as being able to afford the associated costs of attendance at the university.

8.1 | STEM-SPSI instrument utility

When considering the student-support efforts in STEM, there is a need for a tool that more directly assists academic units in assessing the type of support students perceive to be receiving (or not receiving). The STEM-SPSI contains items that can be used to evaluate the quality and extent of academic-unit level support provided to STEM students as opposed to event reporting on frequency and quality of engagement, climate, or sense of belonging to an institution. We identified core student-support constructs and tested measures across a range of students in STEM contexts during instrument development, which can be disaggregated as needed.

While results from instruments like RISC could inform practitioners that students are dissatisfied with the career services center on campus, the STEM-SPSI can more readily help practitioners assess how students perceive the career development support provided by a college holistically. For example, the STEM-SPSI includes items within the career development construct of student support that would indicate specific areas for improvement (e.g., interview preparation, opportunities for networking with professionals). In short, although useful in their own right, instruments like RISC and CIRP are designed for university-level evaluations and do not provide specific insights about areas for improvement during evaluation of college-level support efforts.

9 | IMPLICATIONS AND FUTURE WORK

We begin this section by including a consideration of fairness in the use of the instrument. This section is oriented around the following question: *What equitable use guidelines might be necessary to support equitable use of the instrument, particularly as it relates to protecting marginalized students at PWIs?* We created the STEM-SPSI with practitioners and marginalized students in mind. We envisioned the use of this instrument as a diagnostic tool to reveal differences in student support across academic units that are worthy of exploration, even if sample sizes prevent them from being statistically significant. Given the practical intent of the STEM-SPSI, not all decisions were made from a theoretical perspective. We also want to note that this

instrument is not appropriate for use at the individual level. For example, findings should not be used for punitive predictive modeling or flagging an at-risk student if the intention is not to bolster their support system with additional resources. Lastly, we assert that the STEM-SPSI is not intended to blame individual academic units for students' perceptions of low support. In accordance with these considerations, we offer the following implications.

9.1 | Implications for practitioners

Although practitioners are primarily concerned with documenting and evaluating the success of support services, they often rely on educated guesses or student demand to inform decisions on improving student-support services (George et al., 2019; Muraskin, 1997). To support more data-informed decision-making, we have empirically identified elements of student support that colleges may leverage to foster greater success for STEM undergraduates. A reliable taxonomy of student-support services is key for successful evaluation of programs providing student support (Chaney et al., 1997). The STEM-SPSI can help STEM educators identify the need for new interventions and tweak current student-support efforts (e.g., making them more sustainable, efficient, and effective) to add value to strategies that are already in place.

Programs aimed at supporting marginalized students in STEM could be improved with prescriptive and mandated program requirements (Chaney et al., 1997; Estrada, 2014), yet until now there has been insufficient evidence on what those prescriptions and mandated elements should be. Given the use of cocurricular support programs in STEM and the variety of services, experiences, and supports aimed at marginalized students in STEM (Estrada, 2014), the common approach to assess the overall impact of individual programs or services becomes cumbersome and inefficient. Because institutions and academic units only have a limited set of resources that can be spent on support efforts, our hope is that this instrument can provide empirical support for decisions regarding programming that is focused on particular components of support known to influence student success. As such, it is imperative that intentionally designed student demographic questions accompany the instrument. The intake and demographics (2017) survey influenced the items we used to capture student characteristics so that we were sure to follow a comprehensive and inclusive approach.

Although not discussed in this paper, we recommend collecting data on student demographics in a holistic way, as informed by Fernandez et al. (2016). These demographic items allow for a comprehensive collection of race and ethnicity, gender identity, disability or ability status, identification with the LGBTQ+ community, parents'/guardians' level of education, international status as well as discipline, and class standing. In our study, students were allowed to select any group membership to which they self-identified.

As broadening participation remains a challenge, many institutions invest substantial resources to support these students, and having a way to monitor progress beyond enrollment numbers is sorely needed (Estrada, 2014; Muraskin, 1997). Furthermore, assessing student-support services based on overall impact of individual programs hinders the establishment of benchmarks needed for comparing similar support interventions across contexts (Chaney et al., 1997). For example, if an administrator identifies STEM career support as being a weakness in student support relative to other constructs, new programming or partnerships with other institutional units could be targeted toward those kinds of activities instead of other areas under which students perceive adequate support. If certain academic units appear stronger than others for certain constructs, institutions could identify best practices in student support that could be shared across organizational units.

9.2 | Implications for researchers

In addition to supporting the monitoring of local contexts to inform practice and policy, the STEM-SPSI has many implications for research. First, it operationalizes a theory of STEM student-support, and collecting additional data will help determine the generalizability of the M CCS (Lee & Matusovich, 2016) and identify nuances that may need to be adjusted for marginalized STEM students' unique support needs (Estrada, 2014) or for different institutional contexts (Muraskin, 1997). In particular, the STEM-SPSI will enable researchers to further address critiques about Tinto's model, and subsequently the M CCS, about treating different types of integration (i.e., academic and social) as mutually exclusive. By using the STEM-SPSI to measure the various student-support constructs, future researchers will be able to further account for the complexity of student integration factors, identifying which support constructs correlate with which types of integration.

Finally, we often frame STEM as being a monolithic entity, but there is growing literature demonstrating that such an aggregation misses important differences among disciplines, even within engineering (e.g., Knight et al., 2012). The STEM-SPSI will enable interdisciplinary comparisons to understand how perceptions of student support vary across disciplinary contexts (Chaney et al., 1997) and could highlight areas in which science and engineering, for example, may differ contextually—our preliminary analyses have already identified differences between science and engineering across the MCCS constructs from our pilot data. Perhaps thinking about broadening participation in “STEM” may not be the most useful approach if we identify important differences in students’ support needs. Continuous and broad-scale use of the STEM-SPSI will enable us to make nuanced, data-informed recommendations regarding programs, activities, and services that can be leveraged to facilitate the elements of institutional support that appear most promising for specific contexts.

10 | CONCLUSION

In developing the STEM student perspectives of support instrument (STEM-SPSI), we operationalized student support and provide a new tool to the engineering education community to monitor student support. Our hope is that in doing so we have provided student-support practitioners with a tool that can produce insights that will better enable them to offer targeted support that can address the shortcomings in STEM learning environments, particularly as it relates to our ability to adequately support students from marginalized groups.

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APPENDIX A.

Results of final confirmatory factor analysis

Latent variable	Indicator variable	Survey item	Standardized factor loading	SE	Item reliability (r^2)	Construct reliability	Average variance extracted
F1: Academic advising support	Q1_1	I received helpful guidance when planning the path of courses required to earn my degree	0.85	0.03	.71	0.83	0.62
	Q1_2	I received helpful guidance on registering for classes	0.85	0.03	.72		
	N1_5	An academic advisor was available when I needed assistance	0.65	0.04	.43		
F2: Academic peer support	Q1_5	I had access to students whom I could ask for academic assistance	0.67	0.04	.45	0.78	0.53
	Q1_6	I received advice from peers on how to be academically successful in STEM courses	0.74	0.04	.54		
	Q1_10	I had an easy time finding someone to work with on my academic work	0.79	0.04	.63		
	Q1_12	I was regularly around other STEM students who took school seriously	0.71	0.04	.50		
F3: Faculty support	Q2_2	My instructors were available to meet with me if needed	0.74	0.03	.55		
	Q2_9	A majority of my instructors wanted me to succeed	0.82	0.03	.67		
	Q2_12	I receive responses from instructors in a timely manner	0.71	0.03	.51		

(Continues)

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Latent variable	Indicator variable	Survey item	Standardized factor loading	SE	Item reliability (r^2)	Construct reliability	Average variance extracted
	N3_2	My instructors fostered an atmosphere of mutual respect	0.78	0.03	.60		
	N3_3	My instructors provided enough resources to support my learning	0.82	0.03	.66		
	N3_4	I received useful feedback on course assignments from my instructors	0.73	0.03	.53		
	N3_5	My instructors connected class topics to potential careers	0.62	0.03	.39		
	N3_6	I could ask my instructors for help if I did not understand course-related material	0.73	0.03	.53		
F4: STEM faculty connections	Q2_5	I had a STEM faculty member who I consider a role model	0.77	0.03	.59	0.91	0.59
	Q2_6	I was mentored by a STEM faculty member	0.78	0.03	.61		
	Q2_7	I had the opportunity to network with STEM faculty members	0.72	0.03	.52		
	Q2_8	I got to know STEM instructors on a personal level	0.78	0.03	.61		
	N4_1	I knew faculty members in my major who I would feel comfortable asking to write a recommendation letter	0.78	0.03	.61		
	N4_2	I had STEM faculty members with whom I could relate	0.81	0.03	.66		
	N4_3	I had a STEM faculty member with whom I could discuss my personal problems	0.72	0.04	.52		
F5: STEM peer connections	Q4_3	I regularly socialized with STEM students outside of class	0.88	0.03	.78	0.90	0.64
	Q4_4	I regularly socialized with students in my major outside of class	0.79	0.03	.63		
	Q4_5	I met STEM students who are now my friends	0.82	0.04	.68		
	Q4_7	I met STEM students who were experiencing struggles similar to those I experienced	0.73	0.04	.53		

(Continued)

Latent variable	Indicator variable	Survey item	Standardized factor loading	SE	Item reliability (r^2)	Construct reliability	Average variance extracted
	Q4_10	I spent time with STEM students who shared my career goals	0.77	0.03	.59		
F6: Graduate student connections	N5_1	I had the opportunity to get to know a graduate student on a personal level	0.86	0.03	.73	0.92	0.68
	N5_2	I had access to a graduate student who I considered a role model	0.89	0.03	.80		
	N5_3	I received mentoring from a graduate student	0.82	0.04	.66		
	N5_4	I had the opportunity to network with graduate students	0.75	0.04	.57		
	N5_5	I knew a graduate student who I would feel comfortable asking to write a recommendation letter	0.82	0.04	.67		
F7: Out-of-class engagement	Q3_3	I was aware of opportunities to volunteer or participate in community service	0.77	0.03	.59	0.89	0.51
	Q3_4	I was aware of opportunities to be involved in STEM organizations	0.80	0.03	.64		
	Q3_5	I received information about non-STEM organizations	0.70	0.03	.49		
	Q3_8	I was encouraged to be involved in the local community outside of the university	0.60	0.04	.36		
	Q3_9	I had opportunities to participate in out-of-class activities with other STEM students	0.68	0.04	.47		
	Q3_10	I had opportunities to participate in out-of-class activities that fit within my schedule	0.62	0.04	.38		
	N6_1	I received information about joining clubs and teams related to my interests	0.75	0.03	.57		
	N6_2	I was aware of opportunities to gain leadership experience	0.77	0.03	.59		
F8: Student affairs support	N9_1	I lived in a supportive environment during the academic year	0.72	0.04	.51	0.83	0.62

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Latent variable	Indicator variable	Survey item	Standardized factor loading	SE	Item reliability (r^2)	Construct reliability	Average variance extracted
F9: STEM career development	N9_2	I had help dealing with stressful situations	0.91	0.03	.83	0.90	0.47
	N9_3	I had help dealing with family issues (e.g., a sick family member, financial, etc.)	0.72	0.04	.52		
	Q5_2	I received assistance with preparing for career fairs	0.60	0.04	.36		
	Q5_4	I had opportunities to network with professionals in my field	0.75	0.03	.56		
	Q5_5	I met professionals in my field (i.e., those working) with whom I could relate	0.82	0.03	.67		
	Q5_6	I met professionals with whom I could identify based on demographic background (e.g., race/ethnicity, gender, etc.)	0.71	0.04	.51		
	Q5_8	I received feedback on my resume and/or cover letters	0.59	0.04	.34		
	Q5_9	I have received assistance with preparing for interviews	0.65	0.04	.43		
	Q5_14	I was encouraged to apply for internships, co-ops, or research opportunities	0.62	0.04	.38		
	Q5_20	I learned from the professional experiences of individuals in other STEM fields	0.76	0.03	.58		
F10: General career development	N11_1	I had access to a professional I consider a role model	0.68	0.04	.46	0.81	0.46
	N11_2	I had access to a professional from whom I received mentoring	0.63	0.04	.40		
	Q5_12	I received advice on what non-STEM employers are generally looking for in an employee	0.66	0.04	.44		
	Q5_18	I discussed opportunities for pursuing a graduate degree outside of my major	0.71	0.04	.50		
	Q5_19	I discussed opportunities for pursuing a professional degree (e.g., law school, medical, vet, MBA)	0.73	0.04	.54		

(Continued)

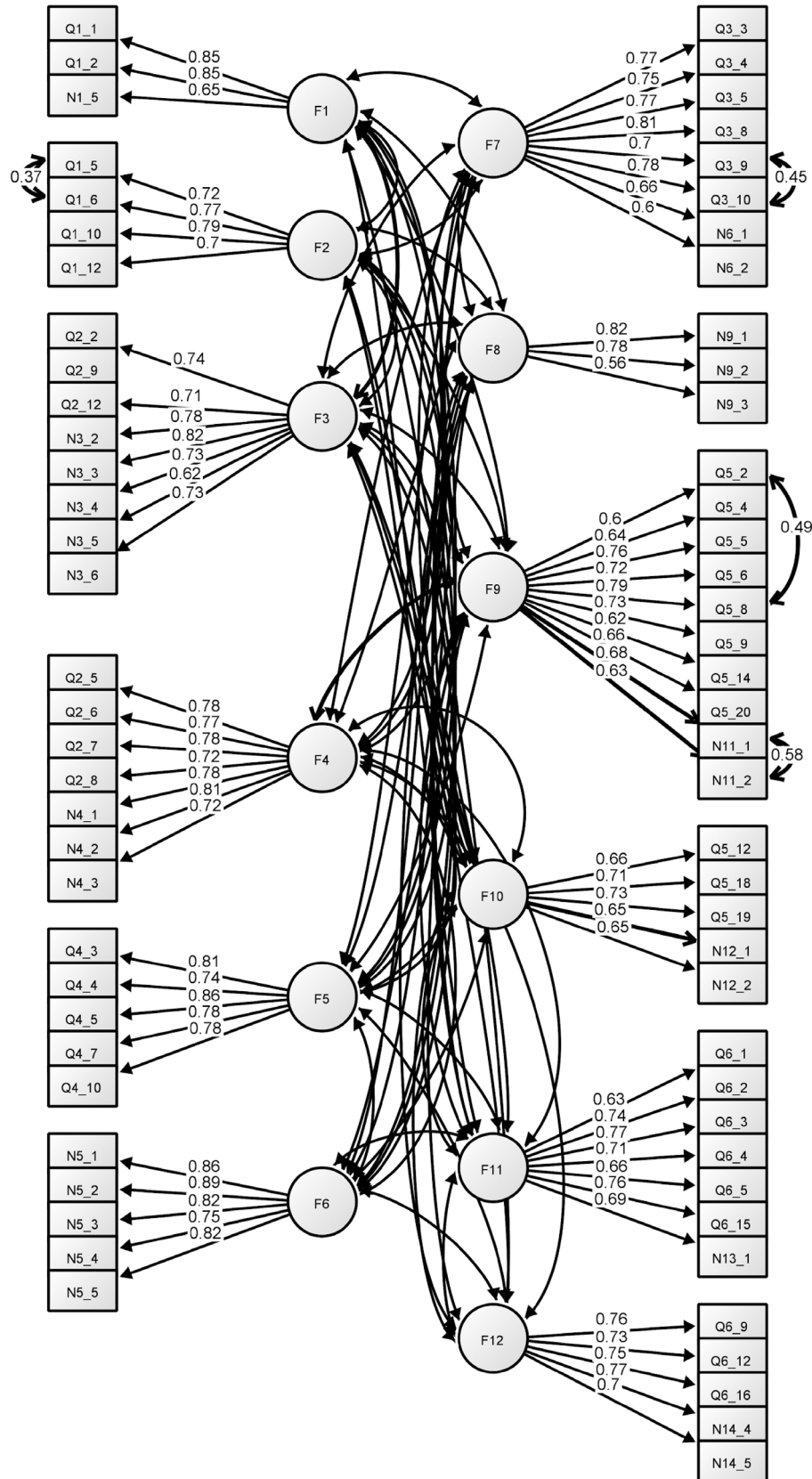
Latent variable	Indicator variable	Survey item	Standardized factor loading	SE	Item reliability (r^2)	Construct reliability	Average variance extracted
	N12_1	I received advice on preparing for a professional examination (e.g., LSAT, MCAT, GMAT)	0.65	0.04	.42		
	N12_2	I was encouraged to explore careers outside of STEM	0.65	0.04	.42		
F11: Cost-of-attendance support and planning	Q6_1	I received the financial assistance that I needed to attend this university	0.63	0.04	.40	0.88	0.50
	Q6_2	I received information about managing student loans	0.74	0.04	.54		
	Q6_3	I received information about scholarship opportunities that applied to me	0.77	0.03	.59		
	Q6_4	I received help in applying to scholarships and/or fellowships	0.71	0.04	.50		
	Q6_5	I received information about work-study programs	0.66	0.04	.44		
	Q6_15	I received information about different types of financial aid (e.g., subsidized loans, unsubsidized loans, grants, scholarships, etc.)	0.76	0.03	.58		
	N13_1	I was encouraged to monitor the status of my student finances	0.69	0.04	.47		
F12: Diversity and inclusion	Q6_9	I received information on the importance of diversity for STEM	0.76	0.04	.57	0.86	0.55
	Q6_12	I received information about overcoming or dealing with prejudice and discrimination	0.73	0.04	.53		
	Q6_16	My college (e.g., College of Engineering, College of Science) was committed to diversity	0.75	0.03	.56		
	N14_4	I was encouraged to learn more about other cultures	0.77	0.04	.59		
	N14_5	I was invited to events celebrating diversity	0.70	0.04	.49		

Note: 1 through 6 (rating scale); 1 = "Does Not Apply to Me," 2 = "Completely Disagree," 6 = "Completely Agree."

APPENDIX B.

Final STEM student perceptions of support instrument (STEM-SPSI)

This image was generated using Ω nyx (Oertzen et al., 2015).



APPENDIX C.

Correlation matrix among factors

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
F1. Academic advising support	–										
F2. Academic peer support	.38	–									
F3. Faculty support	.50	.46	–								
F4. STEM faculty connections	.34	.40	.45	–							
F5. STEM peer connections	.15	.24	.29	.54	–						
F6. Graduate student connections	.42	.55	.48	.42	.31	–					
F7. Out-of-class engagement	.29	.62	.28	.38	.23	.49	–				
F8. Student affairs support	.37	.53	.50	.42	.29	.48	.46	–			
F9. STEM career development	.46	.52	.50	.57	.36	.65	.49	.51	–		
F10. General career development	.29	.28	.32	.47	.46	.48	.29	.34	.53	–	
F11. Cost-of-attendance support and planning	.34	.27	.32	.33	.24	.46	.30	.38	.47	.34	–
F12. Diversity and inclusion	.37	.43	.46	.38	.25	.55	.39	.43	.59	.48	.45