Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45497

Development of a climate survey for engineering doctoral students from an intersectional approach: Second-round validity evidence

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Development of a Climate Survey for Engineering Doctoral Students from an Intersectional Approach: Second-Round Validity Evidence

Abstract

This paper describes the ongoing development of a multi-factor organizational climate scale for engineering doctoral students. Organizational science combined with an intersectional approach can help identify the climates contributing to students' organizational commitment and retention, especially among students from historically-excluded groups. Following initial scale development, which piloted the scale with 287 engineering doctoral students from 28 U.S. institutions, followed by phenomenological interviews with 11 students with minoritized sexual identities in 2023, we administered a revised scale to n = 288 students from 12 U.S. institutions in 2024. Intersectionality guided the identification of climate constructs, the creation of items for the constructs, and the refinement of those items based on preceding phenomenological interviews. The revised scale comprised 43 items assessing eight focused climates. Exploratory factor analysis identified six latent factors, such as perceived cultural diversity, diversity, performance, authenticity, organizational support, and psychosocial safety with 36 items. Although the literature differentiates between psychological safety climate and mastery climate, the items for the two constructs did not group together. Therefore, these scale items will be revised for the next round of validity study. The six factor scale showed excellent internal consistency reliability. Results from this scale have practical implications, indicating specific policies, practices, and procedures that shape doctoral student retention and commitment to degree completion.

I. Introduction

The increased participation of diverse historically-excluded groups (including but not limited to women, Black, Hispanic/Latinx, Indigenous and queer students) in STEM is imperative to maintain the U.S. standing as a global leader in innovation and has the potential to reduce educational, social, and economic inequalities [1]. Currently, the engineering doctoral pipeline does not reflect the diversity of the U.S. population. For example, in 2023, 2.3% of engineering doctoral degrees awarded in the U.S. were earned by American Indian, Black, Native Hawaiian and Other Pacific Islander, Hispanic, or multiracial women [2]. Note that while 55.5% of the degrees were awarded to international students (41.1% to men and 13.4% to women), 17.5% of engineering PhDs were awarded to White men, 7.1% to White women, 4.6% to Asian American men, 2.1% to Asian American women, 2.6% to Hispanic men, 1.3% to Black men, 0.08% to American Indian men, and 0.03% to Native Hawaiian and Other Pacific Islander men [2].

Our NSF-funded collaborative project combines an intersectional approach with organizational science to identify specific climates contributing to the retention and commitment of students from historically-excluded groups. We developed a scale to assess eight climate constructs relevant to students' experiences with department-level organizational climate. Based on the findings from the initial scale development [3] and the initial qualitative interview [4], we revised the scale to assess eight climate constructs indicated by 43 items.

This study addresses the following research questions:

1. *To what extent does the* ***construct validity*** *evidence of the revised climate scale hold for engineering doctoral students?*
2. *What is the level of* ***internal consistency reliability*** *of the revised climate scale for engineering doctoral student data?*

II. Theoretical Frameworks

This project is grounded in an organizational science framework [5-7], which defines *organizational climate* as the shared meaning that organizational members attach to the events, policies, practices, and procedures they experience and the behaviors they see being rewarded, supported, and expected . While general measures of the overall feel or environment have long been used in higher education under the rubric of "climate" (e.g., [8]), such measures cannot provide a clear or useful guide for higher education leaders' decision-making. By contrast, an organizational science approach to climate can identify the policies, practices, and behaviors that contribute to retention [9]. Specifically, a *focused climate* refers to a climate pertaining to a specific outcome or process, such as diversity or psychological safety [6].

Measures of focused climates need an explicit and specific level or frame of reference, such as a lab, department, or university. Without that frame of reference, climate survey respondents are free to interpret questions, perhaps describing perceptions of different parts of their environment at different levels and not necessarily the specific level being studied or targeted. Here, we focus on climate in the *department* because disciplinary, institutional, and professional contexts converge at that level to shape graduate student experiences [10-12].

We incorporated an intersectional approach to guide our scale development process. While the concept of intersectionality has a rich intellectual history originating in 19^{th}-century Black feminist activism [13-16], *intersectionality theory* is typically credited to legal scholar Crenshaw [17, 18], who noted that analysis of race or gender alone fails to capture the experiences of Black women as members of a group constructed by multiple interconnected systems of oppression. Importantly, today the reach of intersectionality theory extends beyond the study of Black women, offering an approach to understanding complex inequities tied to multiple social categories (e.g., gender, race, sexuality) that are embedded within and perpetuated by multiple interconnected systems of oppression [19]. As both a critical theory and approach, intersectionality is fundamentally concerned with social inequality, including access to and full participation in doctoral engineering education.

An intersectional approach is essential when considering engineering doctoral student retention, attrition, and organizational climate. At this stage in our project, intersectionality guided the identification of climate constructs, the creation of items for the constructs, and the refinement of those items based on preceding phenomenological interviews. We identified climate constructs especially relevant to members of historically-excluded groups in that the climates may confer power or contribute to social inequality [20]. Our intersectional approach also shaped our assessment of engineering students' demographic characteristics and, in future stages—when the sample size is larger and statistical power permits—will inform the quantitative data analytic strategies, such as measurement invariance followed by intersectional group comparisons, as recommended by Else-Quest & Hyde [21].

To identify *organizational climate constructs most relevant to engineering doctoral student retention*, we undertook several steps as guided by Clark and Watson [22]. We reviewed the organizational climate literature and identified several specific climates associated with organizational member retention and commitment. We examined studies of climate and STEM doctoral student retention. Our review demonstrated that STEM doctoral student climate studies' constructs were not defined, ill-defined, or derived from literature outside of organizational science [23]. We also noted that studies purportedly of climate utilized survey instruments that were not validated either for the climate constructs they claimed to measure or for assessment across multiple intersectional groups of students. Therefore, drawing reliable conclusions from these studies or translating their results to inform department policy or practice was difficult.

Based on our intersectional approach and literature review, we identified eight focused climates theorized to be relevant to engineering doctoral student retention. Table 1 presents the climates and defines each in the context of our study with supporting literature. Each climate encompasses a process or outcome relevant to all doctoral students, but especially to students from historically-excluded groups. For example, *authenticity climate* captures the perception that one can safely express one's social identities (e.g., sexual orientation), and *psychosocial safety climate* measures perceptions of the organization's commitment to protecting members' psychological health and wellbeing.

Table 1. *Definitions of the Eight Climates in the Scale*

Climate	**Definition**	**References**
Perceived cultural diversity	Perception and accurate recognition of the degree and nature of group diversity, including variety in cultural values, beliefs, and practices	[24, 25]
Diversity climate	Perceptions about the extent to which their organization values diversity as evident in the organization's formal structure, informal values, and social integration of underrepresented members	[26, 27]
Psychological safety climate	Perception of how others in the workplace will respond to risk-taking behaviors, such as taking initiative or speaking up about problems in the workplace	[28, 29]
Mastery climate	Perception that efforts, sharing, and collaboration are valued, and learning and skill development are emphasized in an organization	[30, 31]
Performance climate	Perception that competition with comparison to, and recognition from others are the standards for success.	[32, 33]
Authenticity climate	Perception that the organization encourages and provides a safe environment to express personal identities at work.	[34, 35]
Organizational support climate	The extent to which the department values students' contributions, provides them with support, and cares about	[36-38]

	their well-being	
Psychosocial safety climate	Perception of the support and commitment to psychological well-being and to the prevention of psychological distress due to work demands and stress	[39, 40]

III. Method

A. Scale Revision

During the previously reported initial scale development [23], we systematically reviewed the literature for scales that measure the climate constructs. During the summer and fall of 2023, we collected our first pilot study data [3] to evaluate construct validity evidence from the climate scale for seven constructs indicated by 41 items. An exploratory factor analysis (EFA) revealed the latent factor structure of the scale for six climates. Internal consistency reliability evidence was excellent with an overall Cronbach $\alpha = 0.928$ for 39 items. However, items did not group to indicate *psychological safety climate*, and eight pairs of items presented multicollinearity (i.e., strong correlations over 0.85) [41].

Based on the pilot 1 EFA [3], we revised items for the psychological safety climate construct and items presenting multicollinearity. We added *psychosocial safety climate* to our scale based on findings from 11 interviews with queer engineering doctoral students (see Table 1). Therefore, the climate scale for engineering doctoral students was revised to assess eight constructs indicated by 43 items.

B. Participants

We obtained IRB approval for use of the revised scale and then invited students in engineering doctoral programs at 12 universities to participate in a climate survey during the spring and summer of 2024 [20]. These public research universities were purposefully selected because they are among the top institutions awarding the highest percentage of doctoral degrees to women and racially-minoritized (i.e., Black, Hispanic/Latinx, Indigenous) students. They are situated within nine states, representing the West Coast, Midwest, Southwest, Southeast, and East Coast of the U.S.

Students who completed the survey had a chance to receive a $25 gift card as an incentive. A total of $n = 477$ students responded to the online survey on Qualtrics, and $n = 288$ engineering doctoral students provided valid responses on the survey. The mean age of the participants was $M = 27.73$ years ($n = 282$, $SD = 4.58$), ranging from ages 22 to 52. Students reported an average of $M = 2.84$ years ($n = 282$, $SD = 1.63$, ranging from 1-10) in the doctoral program. Table 2 provides an overview of participants' gender identity, sexuality, race/ethnicity, residency status, first-generation vs. continuing-generation status, and disability status. Here, *first-generation* students are defined as those whose parents or guardians have not earned a bachelor's degree, and *continuing-generation* students are defined as those who have at least one parent or guardian with a bachelor's degree or higher.

Table 2. *Demographic Characteristics of Participants* ($N = 288$)

Category	**Subcategory**	***n***	***%***
Gender Identity	Woman	116	40.3
	Man	161	55.9
	Trans, Genderqueer, Genderfluid, Nonbinary, or Unsure	7	2.4
Sexuality	Queer/sexual minority (e.g., lesbian, gay, bisexual, asexual, pansexual, & questioning)	41	14.2
	Straight	227	79.1
	Prefer not to answer	18	6.3
Race/ Ethnicity (domestic students only)	American Indian/Alaska Native/First Nations/Indigenous	2	0.7
	Native Hawaiian or Other Pacific Islander	0	0.0
	Asian	8	2.8
	East Asian (e.g., Chinese, Japanese, Korean, Taiwanese)	10	3.5
	South Asian (e.g., Afghan, Indian, Pakistani, Sri Lankan)	2	0.7
	Black or African American	4	1.4
	Hispanic or Latino/Latina/Latine/Latinx	18	6.3
	Multiracial	3	1.0
	Middle Eastern or North African	5	1.7
	White	100	34.7
	Prefer not to answer	4	1.4
Residency Status	Domestic (U.S. citizen or permanent resident)	158	54.9
	International	129	44.8
First Generation	First generation student	79	27.4
	Continuing generation student	203	70.5
Disability Status	At least one disability	28	9.7
	No disabilities	249	86.5

Note. Due to the multiple responses and non-responses, the total number of the responses in each category may not add up to 288.

C. Data Analysis

For this study, we conducted an EFA using data from 288 engineering doctoral students to identify underlying factor structure and irrelevant items that did not fit into any factors in the scale. Before conducting the EFA, we calculated Pearson correlation coefficients among the 43 items to check whether the coefficients were positively or negatively correlated, meaning that putative factors identified through an EFA are not independent. We checked for multicollinearity (i.e., strong correlations over 0.85) between two items [41].

We calculated eigenvalues and factor loadings after an oblique rotation of GEOMIN, the default rotation of the M*plus,* to determine the number of factors and items for each factor. We extracted the number of factors underlying the data based on eigenvalues over 1.0 and the point of inflection of the curve in the scree plot [42]. We considered items with a factor loading greater than 0.40 significant for the designated factor [43]. This cutoff functioned to suppress irrelevant items that did not fit well into the designated factor. M*plus* performed full information maximum-likelihood estimation for missing responses under the assumption of missing at random. We calculated the reliability coefficient of internal consistency, Cronbach's α, using

SPSS Statistics 29 [44], and examined how items are inter-related within each factor and the overall instrument.

IV. Results

A. Latent Factor Structure of the Climate Scale

Pearson correlation coefficients among the 43 continuous variables (i.e., items) revealed that the coefficients ranged from -0.465 to 0.907, meaning that some items showed multicollinearity with other items [41]. We extracted six factors underlying the data based on those criteria to determine the optimal number. The exclusion criteria for cutoff factor loading yielded 36 items, excluding seven items (see Table 3). Based on the constructs in Table 1, we matched the constructs to the factors clustered with a group of items. Here, seven pairs of items presented multicollinearity in three constructs. Most multicollinearity occurred among items targeting psychosocial safety climate, indicating that these items tended to capture similar aspects of the construct.

Table 3. *Results from Exploratory Factor Analysis (n = 288) on the Climate Scales*

Construct	Sample Item	Item #	Factor Loading					
			1	2	3	4	5	6
Perceived cultural diversity	*My department includes people from many different and distinct cultures.*	1	**0.907***	-0.006	0.066	-0.019	-0.015	-0.019
		2	**0.844***	0.114*	-0.018	-0.064*	0.016	0.004
		3	**0.879***	0.019	-0.007	0.025	-0.001	0.039
		4	0.433*	0.350*	0.031	0.016	0.102	0.035
Diversity climate	*The goal of increasing diversity in my department is taken seriously.*	5	0.147*	**0.751***	-0.059	-0.030	0.028	-0.032
		6	-0.013	0.360*	0.285*	-0.075	0.235*	-0.128*
		7	0.090*	**0.735***	0.090	0.010	0.018	0.049
		8	-0.013	**0.810***	0.064	0.019	0.008	0.064
		9	0.013	**0.837***	-0.002	0.022	-0.010	0.147*
		10	0.175*	**0.625***	0.078	-0.045	0.012	0.007
		11	0.031	**0.817***	-0.012	0.011	-0.006	0.111*
		12	0.104	0.200*	**0.535***	-0.060	0.027	-0.074
Psychological safety climate	*It is easy to ask for help from my department.*	13	0.047	0.121*	**0.460***	-0.064	**0.257***	-0.086
		14	0.142*	0.071	0.356*	0.012	0.183*	0.000
		15	-0.096	**0.292***	**0.414***	-0.054	0.140	0.033
		16	-0.023	0.202*	**0.487***	-0.018	0.182*	-0.030
Mastery climate	*My department encourages and values doctoral students' skills development.*	17	0.040	0.019	**0.780***	-0.099*	0.005	-0.011
		18	-0.027	0.075	**0.517***	0.004	-0.058	0.193*
		19	-0.036	0.126*	**0.574***	0.037	0.120	0.160*
		20	-0.048	0.007	**0.544***	0.008	**0.259***	0.150*
		21	0.027	0.000	**0.803***	0.006	0.064	0.035
Performance climate	*My department encourages rivalry between doctoral students.*	22	0.011	0.017	0.082	**0.695***	-0.122	-0.044
		23	0.000	-0.026	0.009	**0.936***	0.025	-0.020
		24	0.018	-0.022	-0.091	**0.907***	0.064	-0.029
		25	-0.100	0.029	-0.024	**0.511***	-0.175*	-0.021
		26	-0.055	-0.006	-0.001	**0.653***	-0.158*	0.006
	My department has policies to protect	27	0.052	0.107	0.149*	0.047	**0.511***	0.103
		28	-0.003	-0.071	-0.011	-0.074	**0.809***	0.035

Authenticity climate	*students' self-expression.*	29	0.027	-0.002	0.072	-0.011	**0.803***	0.089*
		30	0.024	0.078	0.045	-0.017	**0.802***	-0.011
		31	-0.008	0.134*	0.058	0.007	**0.679***	0.066
Organizational support climate	*My department considers doctoral students' goals and values.*	32	-0.030	0.106	**0.628***	0.024	-0.104	0.123
		33	0.049	-0.017	**0.478***	0.077	0.076	**0.248***
		34	0.048	0.012	**0.571***	0.007	0.069	0.033
		35	0.072	-0.200*	**0.702***	-0.029	0.032	0.082
		36	0.142*	-0.072	**0.600***	0.044	-0.058	0.209*
		37	-0.018	-0.008	**0.523***	0.000	0.202*	0.025
Psychosocial safety climate	*My department shows support for stress prevention.*	38	0.049	0.061	0.024	-0.114*	0.071	**0.706***
		39	-0.045	0.078*	0.072	-0.056*	0.116*	**0.724***
		40	0.023	0.139*	0.060	-0.033	0.010	**0.700***
		41	0.011	0.029	-0.047	0.018	0.043	**0.911***
		42	0.011	-0.076	0.047	-0.028	-0.005	**0.898***
		43	0.001	-0.004	0.036	-0.061*	-0.009	**0.865***

Note. $^{*}p < 0.05$.

B. Reliability Evidence of the Climate Scale

We utilized data from $n = 288$ engineering doctoral students for the reliability analysis. Six constructs appeared to have good internal consistency; Cronbach's α values ranged from 0.890 to 0.966 (see Table 4). However, two intended constructs (psychological safety climate and mastery climate) grouped together and were excluded from the reliability analysis.

All 36 items were worthy of inclusion because removing any item would not increase the reliability for any construct or the scale as a whole [45]. Table 4 shows the initial number of items and the number of items grouped for latent factors resulting from EFA.

Table 4. *Number of Items and Internal Consistency Reliability Evidence of the Climate Constructs*

Intended Constructs	n_i	**Identified Constructs**	n_{EFA}	**Items Retained**	**Cronbach's α**
Perceived cultural diversity	4	Perceived cultural diversity	3	1, 2, 3	0.935
Diversity climate	8	Diversity climate	6	5, 7, 8, 9, 10, 11	0.946
Psychological safety climate	4	Psychological safety climate	0	N/A	N/A
Mastery climate	5	Mastery climate	0	N/A	N/A
Performance climate	5	Performance climate	5	22, 23, 24, 25, 26	0.890
Authenticity climate	5	Authenticity climate	5	27, 28, 29, 30, 31	0.935
Organizational support climate	6	Organizational support climate	11	12, 16, 17, 18, 19, 21,32, 34, 35, 36, 37	0.938
Psychosocial safety climate	6	Psychosocial safety climate	6	38, 39, 40, 41, 42, 43	0.966
Total	43		36		

Note. n_i = The initial number of the items in the construct; n_{EFA} = The number of items grouped for a latent factor resulting from EFA; N/A = Not applicable

V. Discussion

The EFA revealed the latent factor structure of the climate scale for six climates indicated by 36 items. Although we expected to have two distinct constructs for psychological safety climate and mastery climate, the items for the two constructs did not group together. Therefore, we plan to revise these scale items for the next round of validity study, as the literature differentiates between these constructs (See Table 1). Internal consistency reliability evidence for the remaining six scales was excellent. The survey data were used to inform the second round of 16 phenomenological interviews with a subsample of participants from multiply-marginalized groups during fall 2024 [46].

Our combination of organizational science with an intersectional approach set this project apart from existing climate research in higher education and attempts to bolster student persistence in doctoral engineering. With a foundation in organizational science, we are introducing focused climates associated with member retention into doctoral engineering. A focused organizational climate approach can facilitate intervention efforts aimed at improving specific department policies, practices, and procedures, such as instructional practices, professional development offerings, the process to change advisors, and grievance and non-retaliation policies, to name a few. Viewing engineering doctoral student retention as an organizational science issue would also shift the responsibility from the faculty advisor-advisee relationship, which is often considered pivotal from a student-persistence perspective, to higher education leadership who are positioned to drive organizational change.

Likewise, intersectionality informed our choices throughout the research process, beginning with our explicit goal of amplifying the voices of students from multiple historically-excluded groups. We sought to recruit students from a diverse sample of engineering doctoral programs and maximize our sample from multiple historically-excluded groups. Thus, our sample does not proportionally represent the population of U.S. engineering doctoral students. Women are overrepresented in our sample (40.3%), which supports our intersectional goal of amplifying the voices historically-excluded groups in engineering.

And, in positing that organizational climate in doctoral engineering is ripe for intersectional analysis, we identified climates relevant to all students, but especially so for members of historically-excluded groups insofar as those climates have the potential to confer power and contribute to inequality. For example, a strong diversity climate reveals the departments' commitment to including students from diverse groups; diversity confers benefits to all organization members but also makes clear that students from historically-excluded groups are welcomed. Intersectionality will continue to guide our data collection and analysis. Future data collection efforts will warrant larger samples that are diverse and oversample low-frequency groups (e.g., students with disabilities) to facilitate complex group comparisons. Similarly, we will test for measurement invariance to identify any potential bias in items toward specific groups.

Based on the second round validity evidence reported here, we will continue to revise the climate scale. The finalized survey will help leadership implement actions to enhance departmental climates and create a more diverse doctoral engineering workforce. Future higher education climate research must be grounded in and guided by contemporary organizational climate science to provide actionable results and promote systemic changes that broaden participation of students from historically-excluded groups.

Our project is informed by scholarship and expertise in organizational psychology, engineering education, educational measurement, and feminist science. We caution against a siloed approach to climate research in engineering doctoral departments. In particular, organizational climate studies require an interdisciplinary team approach that should include organizational psychology experts in the climate area of interest. The engineering education community should not simply incorporate existing organizational climate scales into their research, but rather develop measures that capture the uniqueness of doctoral engineering education. Likewise, research projects aiming to study or compare historically-excluded groups require a reflexive, critical approach that attends to the social context of intersecting systems of oppression without essentializing social categories or group differences.

Acknowledgment

This work was supported by the National Science Foundation under collaborative grant numbers 2201100, 2201101, 2201102, and 2201103. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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