Critical Mass or Critical Culture?

Gendered Perceptions of Women and Men in an Engineering School

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***Abstract*— Your school reached its target percentage for women in engineering. So what? And now what? With all the discussion and reporting of *percentages* of women in engineering, educators may be tempted to assume that attaining a target number, or 'critical mass,' alone solves the problems related to engagement of a gender diverse student body. We argue that while critical mass may be necessary, it is insufficient. We submit that a thriving and diverse learning ecosystem must recognize the importance of *interactions, associations, values,* and *identities* in shaping a culture of inclusiveness. To that end, in this study we characterized the motivations, professional identities, basic needs satisfaction, and self-efficacy of undergraduate students in an engineering school with a relatively high percentage of enrolled women. In this environment that passes common critical mass thresholds, we observed gendered responses that call into question the use of simple percentages as proxies for inclusiveness in engineering. Specifically, we found that women and men held some common values, and similarly endorsed certain identity traits such as problem solving and practicality. Compared to men, however, women reported lower self-efficacy, lower endorsement of technological leadership, higher emphasis on social consciousness, and less freedom to express their ideas and opinions. These findings raise important questions about inclusive design of engineering cultures, and they help illustrate where women and men may find personal and professional alignment versus misalignment in their programs.**

Keywords—gender; diversity; inclusion; identity; motivation; basic needs satisfaction; self-efficacy

I. Women and Engineering Learning Culture

Engineering education is not succeeding in creating a diverse and inclusive environment. Billions of dollars spent on initiatives aimed at increasing the percentage of women and other underrepresented groups in engineering [1] have resulted in little gain over the past 20 years. For example, the percentage of engineering bachelor's degrees earned by women was 20.5% in 2000, 18.4% in 2010, and 19.9% in 2015 [2,3]. Engineering's lack of progress in gender diversity stands in stark contrast to fields such as architecture, agriculture, and biology, which have all realized dramatic positive shifts the last few decades [4]. Engineering educators are striving to understand these diversity challenges, and researchers are actively exploring the question of whether the *culture* of engineering is able to support the engagement and well-being of a diverse group of learners, or if engineering culture requires a fundamental shift or redesign. Despite engineering's overall lack of progress, a few schools have succeeded in attracting and retaining relatively high percentages of women [3].

Engineering schools often cite numeric gender ratios in their discussion of diversity goals [e.g., 5,6,7], and some engineering educators are drawn to the concept of 'critical mass' of underrepresented groups as an indicator of success or failure [e.g., 8]. Critical mass is just a number, however, and the impacts of crossing a particular numeric threshold are not entirely clear [9, 10]. What is clear is that numbers cannot represent the beliefs, values, actions, identities of people in majority or minority populations, or shed light on cultural shifts required to support a more diverse and inclusive ecosystem. Change requires more than a targeted numeric percentages [11,12]; it demands a deep understanding of cultural norms that may promote marginalization and drive exclusion of certain groups [13,14]. In this paper, we consider critical mass concepts in light of research that examines how cultural norms interact with learner identities and values to influence engagement. We do this by analyzing the responses of women and men in a school that meets the critical mass threshold but sustains certain gendered perspectives on engineering and engineers in its programs. We argue that while critical mass is important to the diversity and inclusion puzzle, it is by no means sufficient. We suggest that a deeper understanding of engineering's cultural norms and a stronger focus on creating *critical cultures* of inclusion are necessary to prompt meaningful change in our systems.

A. *Critical Mass Theory*

Critical mass is an oft-cited but somewhat misunderstood concept in engineering education. The basic critical mass concepts presented by Kanter [15] are simple: (i) group dynamics are influenced by proportional representations of people of different social or cultural type, (ii) numerically dominant groups tend to control social interactions and culture, and (iii) a threshold proportion of majority to minority must be crossed to shift the group's interaction dynamics, behaviors, and culture in a way that changes individuals' experience. Although Kanter draws attention to a range of important social phenomena such as status, power structures, gendered work norms, visibility, polarization, isolation, retaliation, majority solidarity, role entrapment, and assimilation, her theory ultimately rests on a 'form determines process' assumption that numerical proportions will drive cultural shifts [15]. Understandably, some educators take this to mean that attaining a certain threshold percentage is paramount, and that once critical mass is numerically attained, inclusiveness and equity will emerge. This viewpoint, while simple and attractive for strategic goal setting, misrepresents the critical mass research in several important ways. First, critical mass theory

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offers little clarity regarding the 'tipping point' ratio required for change, despite its reliance on proportional representation as the key determinant of cultural shifts. Kanter described *skewed* groups (85:15 ratio) and *tilted* groups (65:35 ratio) along a continuum of representation, but she did not identify a particular ratio necessary for change. Researchers have since defined critical mass ratios ranging from 15 to 40 percent [16,17,18], making it difficult to put too much weight on one value. Second, Kanter only examined a single skewed group to determine women's responses in a corporate setting dominated by men. The study illustrated negative patterns but offered few insights into the *mechanisms* or 'critical acts' [18] that might lead to positive cultural change. Finally, critical mass theory seems to place enormous pressure on the minority population as the impetus for change, rather than examining how the dominant group might play a role in actively shifting culture [19] or lowering resistance to change [20].

B. From Critical Mass to Critical Culture

Culture is a powerful force that is self-promoting and resistant to dismantlement. Research on engineering culture, gender, and identity illustrates that male-dominated fields sustain robust and deeply embedded beliefs about who engineers are, what engineers do, and how engineers behave, and that gendered cultural patterns in engineering learning settings can threaten diversity and inclusion regardless of whether minority groups attain substantive representation. The gender and culture issues in engineering operate at many levels. On the surface lie gender ratios, cultural symbols and overt language that position women in engineering as exceptional or unusual – even *intrusive* [20] or *threatening* [21] – and that may ask women to explain why they chose or how they fit engineering [22], or pressure women to assimilate or conform to preexisting social and cultural patterns [15,23]. No such demands are placed on men in engineering [22].

On a deeper level lie gendered beliefs about what it takes to be professionally capable in engineering, and who is equipped to develop these capabilities. Research shows that gendered typing of engineering abilities causes stereotypically feminine competencies such as ethics, social consciousness, health and safety, diversity, and communication to be devalued or marginalized by men, despite centrality of these competencies to engineering practice [24,25]. This gender-based stereotyping of engineering competencies and discounting of anything that is 'soft' is enormously problematic. Most engineers recognize that professional practice involves a heterogeneous mixture of knowledge and skills involving a range of technical, social, instrumental, and expressive capacities [26]. Yet engineers in both industry and academia cling to technical work or 'hard core' subjects [27] as 'real engineering' [28], and embrace 'technicist' engineering identities that regard the technical and social as incompatible [26]. Instructors often gravitate toward dualisms, e.g., technical vs. social, hard vs. soft, reductionist vs. holistic, and concrete vs. abstract [29]; and these dualisms are often coupled to implied or explicit ability hierarchies and gendered associations. Framing engineering in this way privileges men and leaves women excluded or pressured to adopt identities aligned with false dualisms and distorted ability hierarchies; promotes gendered discourse on what counts as good engineering and who counts as a good engineer [30]; and undermines women's professional role confidence and engineering self-efficacy [22,31].

Engineering's gender imbalance is also sustained by more deeply rooted cultural values, beliefs, and systemic structures. Researchers describe engineering as a 'socially constructed profession of masculinity' [32] with entrenched masculine norms of dominance, force, aggression, violence, independence, risk-taking, and authoritarianism [33,34,35]. Combined with a 'determined, willful ignorance' among those in positions of power and privilege [36], some argue that engineering is a profession that is structurally, organizationally, and culturally biased against women [33,34,35]. Given all of the factors working against inclusiveness in engineering, it is reasonable to assume that engineering programs could succeed in attaining their *numeric* diversity goals, only to find that their *culture* remains unwelcome to certain groups. Inclusion, after all, requires more than diverse representation; it requires critical unpacking of existing norms and establishing of new cultural and social conditions that are supportive of everyone [25,37,38]. This study represents an attempt to expand the conversation beyond critical mass as a number, and toward the building of a critical culture that supports diversity in engineering education.

II. METHODOLOGY

This study examines how undergraduates view themselves, the engineering field, and their learning environments, at an engineering school with a relatively high ratio of women. Participants in this study were 329 undergraduate students enrolled in five different engineering programs at a medium-sized private research university in the U.S. The school is listed among the top ten programs for percentage of bachelor's degrees awarded to women [3]. The study sample included 174 men (53%) and 155 women (47%), which represents an oversampling of women compared to the overall gender ratio in the engineering school (63.4% men, 36.6% women).

This study made use of several existing quantitative survey instruments. Students' *perceived values* and *motivations* in engineering were measured with the expectancy-value theory based survey described by Mamaril [39]. *Self-conceptions* and *professional identity associations* were measured using a method defined by Cech [37], which asked students to rate themselves along continua, two of which are stereotypically gendered (unemotional-emotional, and logical-illogical) and two of which are gender-neutral (social-asocial and abstract-general). The professional identity survey component asked students to rate the importance of four professional identity traits: problem-solving prowess, technological leadership, social consciousness, and managerial/communication skills. *Perceptions of engineering program supportiveness* were measured using an adapted version of the Basic Psychological Needs Satisfaction Scale [40], which maps perceptions of the learning environment to three basic needs (competence, relatedness, autonomy) defined by self-determination theory for motivation. *Engineering self-efficacy* was measured using an adapted survey from Bong [41]. For all survey data, descriptive statistics were compiled and differences across gender were analyzed.

III. Results and Discussion

In this section, we highlight several encouraging findings related to women and men's motivations and needs satisfaction, and we discuss the significant gender differences in engineering self-efficacy, self-conceptions, and professional identities that were revealed in our analysis.

A. *Task Value and Motivations*

Women and men showed no significant differences in their perceived intrinsic value, attainment value, utility value, or cost value in engineering, based on the survey subscale means. On specific survey items within the *intrinsic value* and *cost value* constructs, however, men and women responded significantly differently. For example, men reported higher intrinsic valuing of innovative product design and advanced technology development, and more intrinsic enjoyment in reading about technological innovations, understanding how things work, and engaging in engineering design projects. In considering the *cost* of engineering, women more strongly perceived engineering to be a "tough program," compared to men. The specific reasons women find their programs 'tough' were not explored in this pilot study, but prior research suggests that this perception may be tied to gendered ability beliefs, or social or cultural signals in the learning environment [25,30].

B. *Self-Conceptions and Professional Identity*

In the self-conceptions measure (Table I), both men and women perceived themselves as more practical than general, and they rated themselves similarly on the asocial-social continuum. Compared to men, women self-report as more emotional and less logical. Research shows that engineering cultures tend to adopt stereotypically masculine and homogeneous self-conceptions (unemotional, logical), and avoid or devalue those traits deemed feminine, despite the hetergeneous nature of engineering practice [24,26,30,37]. Women who endorse stereotypically feminine traits can at times be trapped in a double-bind, required to choose between rejecting authentic aspects of identity to become more "'like men', and by implication unlike 'most' 'emotional' women" [30], or get pigeon-holed into roles that are "vulnerable to derogation and a quiet hostility" [29,30]. Either choice leads to women having to exert more energy than men to manage their professional identity and gender identity [22].

On the professional identity traits survey, women and men placed similar value on the importance of *problem-solving prowess* and *managerial/communication skills* to a successful engineering career (Table II). Women and men showed significantly different alignment with other engineering traits, however, with men more strongly endorsing technological leadership and women more strongly endorsing social consciousness. These mixed professional identity trait responses are interesting to consider from the perspective of gender and engineering's cultural norms. While engineering cultures place high value on problem solving and technological leadership, social consciousness and managerial and communication skills are often marginalized [42]. Students in this setting appear to have shifted their beliefs about engineering to include managerial and communication skills as part of professional identity. Valuing of these skills may be tied to the school's explicit emphasis on broadly-defined leadership, via various curricular and co-curricular initiatives. Nevertheless, men and women fall into more gender typical positions in their valuing of technological leadership (men) and social consciousness (women). As such, professional identity construction in this setting could trigger gender-related tensions, as students negotiate these differences [26].

TABLE I. Self-Conception Measures. 7-Point Continuum.

Self-Conceptions Subscale	**Men (N=173)**		**Women (N=155)**		***p-value***
	Mean	***SD***	***Mean***	***SD***	
Unemotional(1) to Emotional(7)	3.76	1.43	4.32	1.42	.001
Illogical(1) to Logical(7)	6.05	0.87	5.77	0.96	.015
Asocial(1) to Social(7)	4.65	1.50	4.75	1.54	ns
Practical(1) to General(7)	2.85	1.48	2.67	1.32	ns

ns = not significant

TABLE II. Professional Identity Subscale Responses. Likert Scaled (1=very unimportant, 5=very important).

Professional Identity Trait Measure Personal importance to me of:	**Men (N=173) *Mean***	**Women (N=155) *Mean***	***p-value***
Technological leadership (subscale avg.)	**3.85**	**3.53**	**.000**
a. Making important scientific discoveries	3.38	2.99	.002
b. Creating/managing future technologies	4.07	3.62	.000
c. Inventing new technologies	3.90	3.30	.000
d. Being a leader in my field	4.10	4.06	ns
Social consciousness (subscale avg.)	**3.84**	**4.27**	**.000**
a. Improving society	4.10	4.41	.001
b. Being active in my community	3.74	4.23	.000
c. Promoting racial understanding	3.17	3.80	.000
d. Helping others	4.34	4.65	.000

ns = not significant, .000 represents p<.001

C. *Needs Satisfaction in the Engineering Learning Context*

Men and women report similar basic needs satisfaction in their engineering programs (Table III). Both women and men perceive competence needs as the most satisfied, and autonomy needs as the least satisfied, suggesting that their engineering programs are only moderately supportive of choice and control in learning.

TABLE III. Basic Needs Satisfaction Subscale Averages. Likert Scaled (1=corresponds not at all true, 7=corresponds exactly).

Basic Needs Satisfaction Subscale Averages	**Men (N=173)**		**Women (N=155)**		***p-value***
	Mean	***SD***	***Mean***	***SD***	
Competence	5.15	1.06	4.93	1.05	ns
Relatedness	4.98	1.02	4.94	1.10	ns
Autonomy	4.41	0.88	4.22	0.92	ns

ns = not significant

Although the needs satisfaction survey's subscale averages showed no statistically significant differences between women and men, examination of individual survey items reveals a few gendered responses (Table IV). Women reported that they receive less positive feedback on their abilities, find people in the programs less friendly, and feel less free to express their ideas and opinions in their programs. These responses warrant further attention, given the extent to which psychological needs satisfaction can shape experiences in school and beyond [43,44,45]. Research shows that women may place higher value on social aspects of learning than men [46,47]; yet, male-normed cultures can regard social learning strategies as a weakness [48] and create situations that trigger a gendered sense of exclusion [22,28]. If women *do not feel very competent* or *free to express their ideas and opinions,* and they find people in their program *unfriendly*, their engagement and engineering identity development may suffer [49].

TABLE IV. BASIC NEEDS SATISFACTION SURVEY ITEMS. (1=CORRESPONDS NOT AT ALL TRUE, 7=CORRESPONDS EXACTLY).

Basic Needs Satisfaction Survey: Survey Items with Significant Results	**Men (N=171) *Mean***	**Women (N=152) *Mean***	***p-value***
Competence Items:			
I do not feel very competent in my engineering program [reverse scored].	2.72	3.20	.007
People tell me I am good at what I do in my engineering program.	5.09	4.70	.017
Relatedness Items:			
People in my engineering program are generally friendly to me.	5.88	5.51	.001
I pretty much keep to myself when I am in my engineering program [reverse scored].	3.90	3.45	.023
Autonomy Items:			
I am free to express my ideas and opinions in my engineering program	5.27	4.82	.002

D. Engineering Self-Efficacy

Despite their high representation, women expressed significantly lower engineering self-efficacy compared to their male counterparts (Table V), specifically with regard to confidence in their ability to *master the content in the most challenging engineering courses*, *do an excellent job on engineering-related problems*, *learn the content in engineering courses*, and *earn a good grade in engineering courses*. These responses are aligned with self-efficacy research that shows that women consistently report lower confidence in their own engineering abilities, even when they are successful in their technical programs [50,51,52,53]. Researchers attribute this effect to gendered expectation setting and normed discourse on gendered abilities, which reinforce cultured beliefs about who is capable, spark tensions in interpersonal interactions and intrapersonal identity formation, and place minority groups in the position of proving themselves capable [30,32,53,54].

TABLE V. ENGINEERING SELF-EFFICACY OF MEN AND WOMEN. LIKERT SCALED (1=NOT AT ALL TRUE, 7=VERY TRUE).

Self-Efficacy	**Men (N=173)**		**Women (N=155)**		***p-value***
	Mean	***SD***	***Mean***	***SD***	
Engineering Self-Efficacy	5.80	0.85	5.56	0.74	.006

Since engineering self-efficacy is biased by societal factors beyond the college learning environment, it is difficult to fully attribute low self-efficacy to the culture of a specific program. Understanding how the design of an engineering program's culture serves to cultivate or suppress student self-efficacy is critical, however, given the connections between self-efficacy and learners' psychological needs satisfaction [55], positive academic emotions [56], engagement and performance [39,48], and persistence [52,57].

IV. CONCLUSIONS

We observe distinct differences between women and men's self-conceptions and professional identities in an engineering school with a relatively high percentage of women. Women report as more emotional, less logical, and less self-efficacious, and they show stronger professional valuing of social consciousness. Men more strongly identify with technological leadership in engineering. Our results also indicate that despite making up nearly 37% of the engineering school's population, women have less positive perspectives on their learning environment and lower self-efficacy compared to men. In some ways, this college appears to perpetuate typical gendered values, beliefs, and interactions. In other ways, such as women and men's shared motivations and equal valuing of managerial/communication skills in engineering, the school seems successful in creating a counterculture that shuns certain masculine norms of engineering. Further analysis is required to gauge the school's overall gender inclusiveness, and to determine the extent to which the results are influenced by numerical representation or intentional culture shaping. Since this pilot study focused on one institution, it does not offer insights into how women in settings with less representation may respond, or how gendered cultural patterns outside of college may influence the results.

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