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Understanding Identity among Biomedical Engineering Students and Professionals

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Abstract
As a highly multidisciplinary field, Biomedical Engineering (BME) has a complex and ever-evolving identity. Little is known about how individuals in BME, especially students, perceive how BME intersects with and incorporates other science and engineering disciplines. Additionally, individual identity is recognized as a crucial factor in choosing and persisting in an academic discipline, yet there are few studies examining how individuals in BME professionally identify. Understanding such identities and how they are formed may be valuable in innovating BME instruction to properly meet students' academic and professional needs. This work explores how BME students and professionals view themselves and the field of BME as related to traditional science and engineering influence. This paper presents quantitative analysis of Likert-scale survey data collected from an annual professional meeting held in 2018. A total of 150 survey responses were analyzed, including 63 undergraduate students, 53 graduate students, and 27 professionals. Descriptive statistical analysis reveals that on average, survey participants view BME as both science and engineering to an equal degree and identify strongly as both engineers and scientists. A multi-step regression was constructed to analyze what predictor constructs contribute to a stronger identity for either engineering or science and how these identities influence career path goals and choices. This study shows that recognition from others is a significant predictor of individual identity and that personal interest is a significant predictor of how an individual views BME. Gender was not found to influence professional identity or perception of BME in this study.

1. Introduction

While biomedical engineering (BME) continues to grow as a discipline and the number of programs increase, there continues to be difficulties with defining BME [1][2]. BME incorporates aspects of several science disciplines including biology, chemistry, and physics, as well as traditional engineering disciplines such as mechanical, electrical, and chemical engineering. Biology, in particular, is a distinct discipline separate from engineering, which poses challenges in instructing biomedical engineers [3][4]. A recent qualitative study of undergraduate perceptions of BME highlighted the broad interpretation of BME by students [5]. Additionally, different institutions structure and classify BME departments differently, with many departments partnering with medical schools.

Diverse interpretations of BME by students, programs, and those who ultimately hire BMEs has the potential to negatively impact students pursing BME degrees. Some BME students report that potential employers do not hire BME graduates due to an uncertainty of what to expect from biomedical engineers. Thus, engineering positions in healthcare which are, in theory, well-suited for biomedical engineers, are instead filled with engineers trained in more traditional disciplines such as mechanical or electrical engineering [6].

In an effort to better understand these historically fundamental BME challenges, this paper seeks to explore BME identity. Identity, both personal and social, has been shown to play a role in educational persistence and career decisions. Some studies have examined social identity factors for representation and persistence in engineering but few, if any, have analyzed professional identity of biomedical engineers. Additionally, little has been done to analyze the effect that social identity, family influences, and other factors have on BME professional identity. Such insights may be crucial for developing recruitment strategies for racial minorities, who are disproportionally underrepresented in engineering, to which BME is no exception [7]. This paper specifically examines the intersection of BME perceptions, professional identity, social identity, and educational background. We ask the following research questions of BME students and professionals: (1) How is the field of BME perceived with respect to science and engineering?; (2) How are perceptions of BME influenced by individual identity factors?; and (3) What factors are associated with the development of a strong science and/or engineering identity?

2. Background

Since its conception, BME has been recognized as an engineering discipline unique in its purpose and practice. Early on, BME was recognized for being more deeply aligned with traditional science, biology in particular, than other engineering disciplines [4]. BME's unique position is illustrated in the varied structures of BME programs at institutions around the world. BME programs stem from electrical, mechanical, and materials engineering departments and many programs partner with medical schools [1]. Across different institutions, BME career paths vary, ranging from medical school, graduate school, the medical device industry, the pharmaceutical industry, and more. The broad interpretation of a BME degree is also reflected in students' perceptions of BME. When asked what BME is, BME undergraduates at a large R1 research institution often defined BME as a combination or application of sciences, engineering, medicine, and math [5]. These findings set a precedence for studying how BME students and professionals understand and interpret the field of BME as science, engineering, or a combination of both.

Several different theories and conceptual frameworks have been used to analyze identity within STEM. Multiple identity theory asserts that individuals can be described by a variety of identities, some of which are formed by the individual and others which are imposed upon them [8]. An important tenant of this theory is that individuals inhabit and perform different identities in different contexts [9], with identity centering around what "kind of person" an individual recognizes themselves as or is recognized by others to be. Critical science agency, a student's deeper level of engagement with science), has also been shown to play a significant role in identity development[10]. Specifically, critical science agency theory emphasizes the responsibility a student takes on for their own learning, practice of science, and identity development [10]. In 2010, Hazari et al. developed an identity framework for student 'identification with physics [11]'. The Hazari identity framework consists of four main components (Figure. 1): recognition, interest, performance, and competence [11] [12]. In this framework, recognition is defined as 'recognition by others as being a good physics student' and interest is defined as 'desire/curiosity to think about and understand physics'. Performance and competence are distinguished by the difference between belief in ability 'to perform [a] required physics task' and 'to understand physics content' respectively.

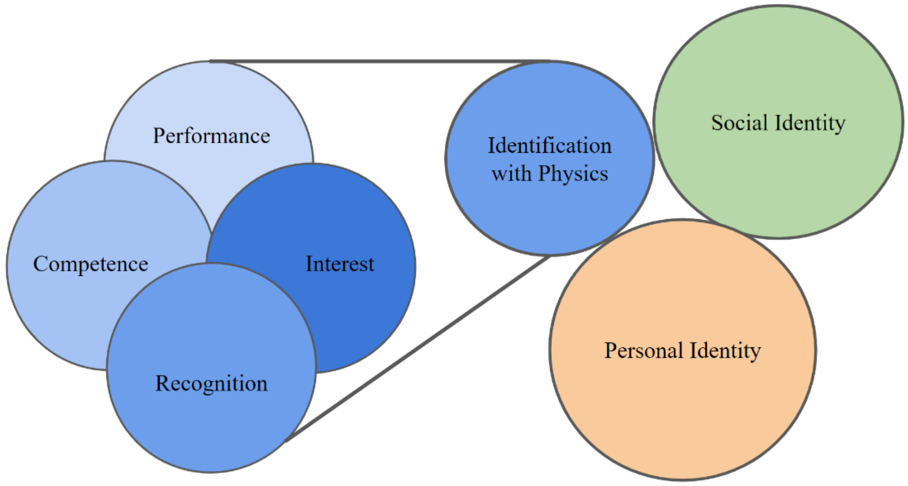

Figure 1: Adapted visualization of Hazari et al.'s framework for 'identification with physics' per critical science agency [11].

In 2013, Godwin et al. used critical science agency and Hazari et al.'s physics identity framework to explore engineering identity as a predictor of engineering major in college [13]. According to Godwin et al., engineering identity relies heavily on strong mathematics and science identities yet should be studied as its own entity, since it plays a key role in predicting student's choice to pursue and persist in engineering. For this study, we leveraged Godwin et al.'s framework to explore three main constructs of BME identity: recognition, interest, and performance/competence [14]. Each of these constructs have been identified as relevant constructs for physics, math, and science identity, all of which are theoretically attributed to engineering identity, as shown in Figure 2. While aspects of Hazari's and Godwin's frameworks have been adapted for studying engineering identity across different engineering majors [15], studies specific to BME identity have not been explored.

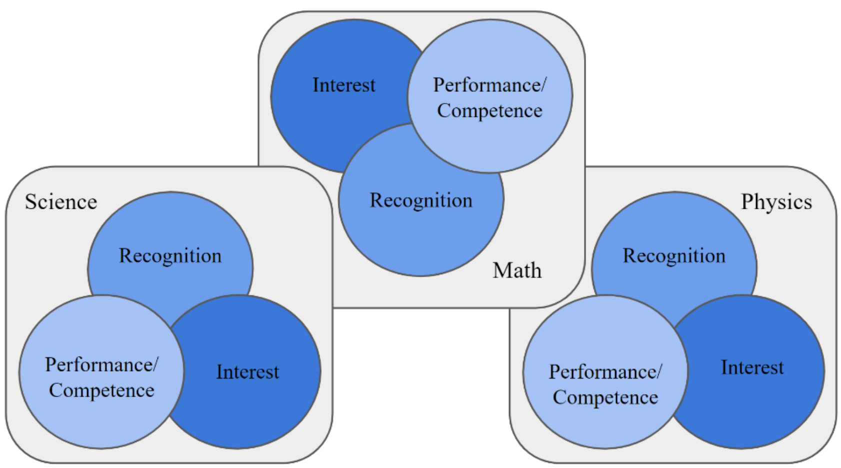

Figure 2: Adapted visualization of Godwin's model of engineering career choice [14].

3. Methods

3.1 Setting and Participants

This study was conducted in 2018 at an annual, international BME conference, predominately attended by trainees. The goals of the conference are to provide early career professional development and communicate BME advances. A 25 question survey exploring participant perceptions of BME and their identity was distributed in exchange for full-sized candy bars. Survey distribution and collection observations indicate that the survey may have been too long and that an electronic version was desired.

A total of 161 participants completed some or all of the survey. One hundred fifty (150) surveys met the criteria of inclusion: complete and valid answers to all direct identity measure questions, specified below, and a response rate of at least 75% for all other questions. A wide range of ages and education levels were represented in the survey sample, but most were under the age of 34. Descriptive statistics are reported in terms of highest education level, rather than current status as student or professional because the focus of the study was on educational influence on identity. Highest education level (current or completed) was determined by the current and/or completed degrees that the participants were asked to list. Participants were divided into two groups:

- *Lower level:* Participants who were currently pursuing an undergraduate degree (63), had completed an undergraduate degree as their highest degree earned (6), were currently pursuing a master's degree (14), or who had completed a master's degree as their highest degree earned (5).
- *Upper level*: Participants who were currently pursuing a PhD (38) or an MD-PhD (1), or had completed a PhD degree (21).

Individuals who completed a masters and those who completed a PhD were separated to account for the extensive research experience that accompanies earning a PhD.

Due to the nature of the data collection setting, data was also analyzed with respect to what types of degrees they were pursuing and/or had earned. Three separate, binary measures were created for three different types of degrees: BME, other engineering, and other science. Participants with 'bioengineering' degrees were coded as having a BME degree. Degrees in a non-science and non-engineering discipline were not considered. Individuals with degrees in more than one category were coded for each category of degree earned. The survey respondents were distributed evenly by gender, with 51.33% women and 48.67% men. All participants specified gender and no non-normative responses were given.

Table 1: Participant demographic data

Demographic	Count	Frequency
Gender		
Women	72	48%
Men	77	51.33%
Not specified	1	0.67%
Race		
URM	30	20%
Non-URM	115	76.67%
Not specified	5	3.33%
Education		
Lower level	88	58.67%
Upper level	60	40%
Not specified	2	1.33%
Degree type		
BME	130	86.67%
Other engineering	46	30.67%
Other science	10	6.67%

3.2 Survey

Eleven survey questions (Appendix) addressing demographics (3), family and educational background (2), career goals (1), and BME identity were analyzed for this study (5). Six of the survey questions were adopted from the Sustainability and Gender in Engineering (SaGE) survey [16],[17]. One question probed family background and the other five questions examined science and engineering identity. The five science and engineering identity questions encompassed 22 items representing six constructs for science and engineering recognition, interest, and confidence (Table 2) and 2 direct measures of the participant's own professional identity ('I see myself as an engineer', 'I see myself as a scientist'). The engineering and science confidence constructs were used to represent the performance/competence measures in Hazari's and Godwin's frameworks. In addition to the items probing participant's own professional identity, an additional question was added to identify perceptions of BME as a field. This question asked participants to rate BME on a 7-point scale from "Mostly Science" to "Mostly Engineering". These three questions were used to represent three direct measures of identity. These three measures are considered direct because they explicitly ask the participant their own view of themselves or the field of BME. Indirect measures of identity were considered those which aimed to measure the three aspects of identity/identity constructs used for our framework, recognition, interest, and confidence. Other studies have treated measures of identity differently, some using identity as a dependent variables and others as an independent variable [12]. We treated the three direct measures of identity solely as dependent variables and the identity constructs as both independent variables (in predicting the direct measures of identity) and dependent variables (predicted by demographic factors).

The identity constructs were tested for internal consistency using Cronbach Alpha and factor analysis. While some constructs, especially 'Engineering Interest', had lower Cronbach Alpha values than is typically accepted, we continued with the constructs as identified.

In addition to identity constructs and demographics, we also examined the presence of potential family influences on participants (family profession). Participants were asked to indicate the professions of several family members (mother/guardian 1, father/guardian 2, siblings, other relative, and spouse) as any of several options (medical/health professional, scientist, engineer, teacher, other science, technology, or math related field, and non-science related career). Each potential profession was treated as its own binary independent variable indicating the presence of that profession among any of the indicated family members.

Table 2: Science and Engineering Identity Construct Reliability

Construct	**Cronbach Alpha**	**Item**	**Factor Loading**
Engineering Recognition	0.793	My peers see me as an engineer	0.910
		My relatives/friends see me as an engineer	0.910
Science Recognition	0.724	My peers see me as a scientist	0.886
		My relatives/friends see me as a scientist	0.886
Engineering Interest	0.570	Applying scientific knowledge to engineering	0.815
		Using engineering to explore scientific phenomena	0.769
		Designing new procedures or devices	0.608
Science Interest	0.692	Understanding science in everyday life	0.822
		Telling others about scientific concepts	0.773
		Making scientific observations	0.773
Engineering Confidence	0.660	I hope to gain knowledge across multiple fields	0.380
		I often learn from my peers	0.423
		I identify relationships between topics from different fields	0.555
		I analyze projects broadly to find a solution that will have the greatest impact	0.534
		I seek input from those with a different perspective than me	0.693
		I seek feedback and suggestions for personal improvement	0.690
		When problem solving, I focus on the relationships between issues	0.693
Science Confidence	0.758	Design an experiment to answer a scientific question	0.733
		Conduct an experiment on your own	0.754
		Interpret experimental results	0.742
		Apply science knowledge to an assignment or test	0.683
		Explain a science concept to someone else	0.660

3.3 Data Analysis

Data analysis was performed using SPSS Statistics 24®. Preliminary data analysis examined the distribution of responses to the three direct identity measures. Further analysis involved independent t-tests and Mann-Whitney U-tests to examine differences in identity by gender, education level, race, and familial. Independent t-tests were used for dependent variables that were normally distributed and Mann-Whitney tests were used for dependent variables that were skewed. Variables with a skewness statistic of less than -1 or greater than 1 were considered skewed. BME perception, individual identity difference, and the science confidence construct were normally distributed while all other identity measures and constructs were skewed.

Finally, we conducted a linear regression for each of the six identity constructs against each of the direct identity measures. The aim of the linear regression analysis was to identify possible relationships between the identity constructs for science and engineering and the direct measures for science identity, engineering identity, and perception of BME while holding all other variables constant. The data were checked for normality, homoscedasticity, and multicollinearity. Normal probability plots confirmed homoscedasticity of the data and normality of the regression standardized residual values. All variance inflation factor (VIF) values were well below 10, indicating that the assumption of the absence of multicollinearity was met.

4. Results

4.1 Preliminary Analysis

Figures 3 and 4 show the distribution of responses to survey questions regarding BME perception and individual identity respectively. On average, participants indicated that BME was nearly equally between '1 - Mostly science' and '7 -Mostly engineering', with an average response of 4.28. On average, participants were also likely to strongly identify both as a scientist and as an engineer.

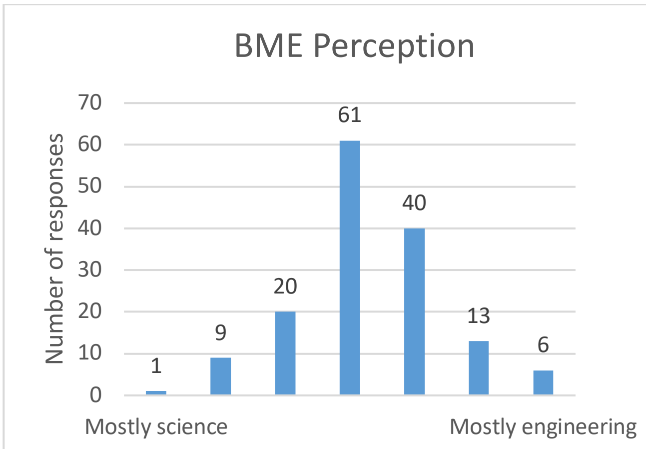

Figure 3: Distribution of BME perception along 7-point scale.

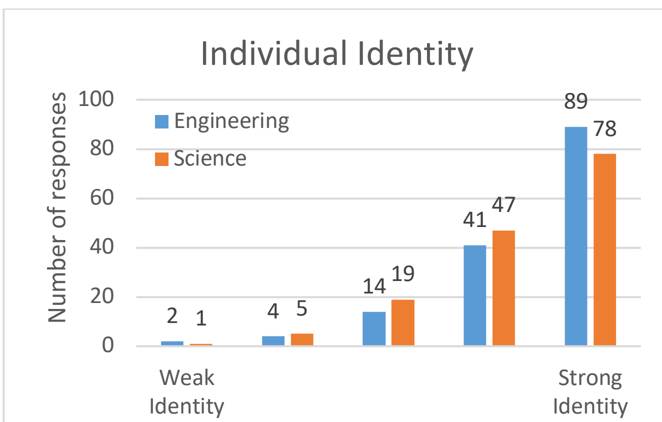

Figure 4: Distribution of individual identity.

For further analysis, individual science identity and engineering identity were plotted against each other to create a science-to-engineering "sliding scale" as with the BME perception measure. We accomplished this by subtracting the participant's science identity value from their engineering identity value. Large negative numbers represent individuals who identify much more strongly with science than with engineering and high positive number represent individuals who identify much more strongly with engineering than with science. Most values fell equally between strong science and engineering identities, ranking them equally or with one 1 point higher than the other. Individual identity skewed slightly towards engineering, with an average difference of 0.10.

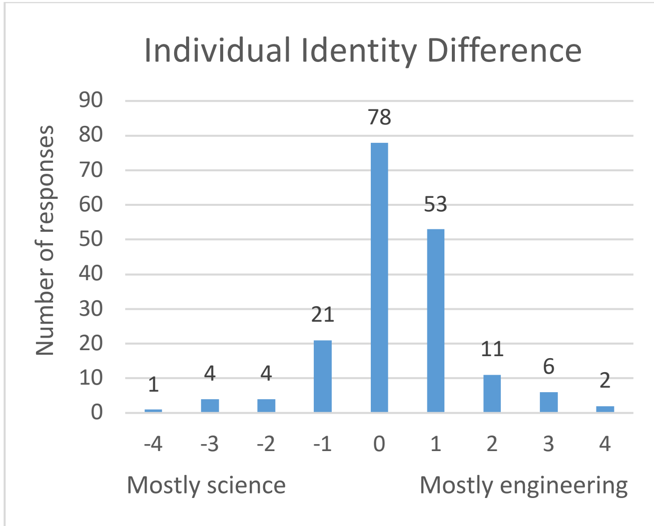

Figure 5: Difference between engineering identity and science identity.

4.2 Differences in Identity

Two sets of tests were conducted to identify differences in identity by gender, education, race/ethnicity, degree type, and family occupation. First, we compared scores for the six identity constructs between each category of our two-category prediction variables. The results of the independent t-tests (science confidence, BME perception and difference between engineering identity and science identity) and Mann-Whitney U-tests (all others) are shown in Tables 3 and 4. The t-test results include sample means ($\bar{x}$), standard deviations (s) and t-statistic (t). The Mann-Whitney U-test results include sample medians, Mann-Whitney U values (U) and z-statistic (Z).

Table 3: Differences in Identity Constructs by Gender, Education, Race, and Degree Type

	Engineering Recognition	**Science Recognition**	**Engineering Interest**	**Science Interest**	**Engineering Confidence**	**Science Confidence**
Gender: (W, M)	$\bar{x}$ = 3.33, 3.36	$\bar{x}$ = 3.14, 3.15	$\bar{x}$ = 3.35, 3.45	$\bar{x}$ = 3.21, 3.45	$\bar{x}$ = 3.32, 3.39	$\bar{x}$ = 3.23, 3.42
Women(W) = 72	m = 3.50, 3.50	m = 3.50, 3.50	m = 3.33, 3.67	m = 3.33, 3.67	m = 3.29, 3.43	s = 0.54, 0.51
Men(M) = 77	Z = -0.204	Z = -0.314	Z = -1.418	Z = -1.29	Z = -1.623	t = -2.207**
Education (L,U)	$\bar{x}$ = 3.40, 3.27	$\bar{x}$ = 3.13, 3.18	$\bar{x}$ = 3.41, 3.37	$\bar{x}$ = 3.17, 3.38	$\bar{x}$ = 3.38, 3.31	$\bar{x}$ = 3.22, 3.50
Lower(L) = 88	m = 3.50, 3.50	m = 3.50, 3.50	m = 3.67, 3.33	m =3.17, 3.67	m = 3.43, 3.29	s = 0.53, 0.50
Upper(U) = 60	Z = -1.251	Z = -0.124	Z = -1.020	Z = -1.709*	Z = -1.055	t = -3.384***
Race (N, U)	$\bar{x}$ = 3.33, 3.40	$\bar{x}$ = 3.22, 2.98	$\bar{x}$ = 3.37, 3.59	$\bar{x}$ = 3.25, 3.43	$\bar{x}$ = 3.36, 3.42	$\bar{x}$ = 3.35, 3.29
Non-URM(N) = 115	m = 3.50, 4.00	m = 3.50, 3.00	m = 3.33, 3.67	m = 3.33, 3.67	m = 3.43, 3.50	s = 0.54, 0.47
URM(U) = 30	Z = -0.273	Z = -1.338	Z = -2.066**	Z = -1.559	Z = -0.803	t = 0.676
Degree Type (Y,N):						
BME	$\bar{x}$ = 3.44, 2.69	$\bar{x}$ = 3.15, 3.17	$\bar{x}$ = 3.40, 3.37	$\bar{x}$ = 3.25, 3.33	$\bar{x}$ = 3.34, 3.42	$\bar{x}$ = 3.32, 3.40
Yes(Y) = 130	m = 3.50, 3.25	m = 3.5, 3.25	m = 3.33, 3.33	m = 3.33, 3.33	m = 3.43, 3.50	s = 0.54, 0.51
No(N) = 18	Z = -1.759*	Z = -0.317	Z = -0.078	Z = -0.337	Z = -1.531	t = 0.597
Other Engineering	$\bar{x}$ = 3.61, 3.23	$\bar{x}$ = 3.04, 3.20	$\bar{x}$ = 3.46, 3.37	$\bar{x}$ = 3.28, 3.25	$\bar{x}$ = 3.32, 3.36	$\bar{x}$ = 3.47, 3.27
Yes(Y) = 46	m = 4.00, 3.50	m = 3.00, 3.50	m = 3.50, 3.33	m = 3.33, 3.33	m = 3.36, 3.43	s = 0.49, 0.54
No(N) = 102	Z = -2.658**	Z = -1.316	Z = -0.684	Z = -0.044	Z = -0.712	t = -2.148**
Other Science	$\bar{x}$ = 2.00, 3.45	$\bar{x}$ = 3.50, 3.13	$\bar{x}$ = 3.27, 3.41	$\bar{x}$ = 3.60, 3.23	$\bar{x}$ = 3.20, 3.36	$\bar{x}$ = 3.46, 3.32
Yes(Y) = 10	m = 2.00, 3.50	m = 3.75, 3.50	m = 3.00, 3.50	m = 3.67, 3.33	m = 3.36, 3.43	s = 0.38, 0.54
No(N) = 138	Z = -3.811***	Z = -1.417	Z = -0.96	Z = -1.676*	Z = -0.069	t = -1.069

*p < 0.1, **p < 0.05, ***p < 0.001

Table 4: Differences in Identity Constructs by Family Profession

Profession (Y, N):	**Engineering Recognition**	**Science Recognition**	**Engineering Interest**	**Science Interest**	**Engineering Confidence**	**Science Confidence**
Medicine/Health	$\bar{x}$ = 3.53, 3.29	$\bar{x}$ = 3.30, 3.10	$\bar{x}$ = 3.52, 3.36	$\bar{x}$ = 3.25, 3.27	$\bar{x}$ = 3.37, 3.35	$\bar{x}$ = 3.30, 3.35
Yes(Y) = 38	m = 3.75, 3.50	m = 3.50, 3.50	m = 3.67, 3.33	m = 3.33, 3.33	m = 3.43, 3.43	s = 0.51, 0.54
No(N) = 112	Z = -1.325	Z = -1.241	Z = -1.446	Z = -0.390	Z = -0.115	t = 0.481
Scientist	$\bar{x}$ = 3.48, 3.32	$\bar{x}$ = 3.46, 3.08	$\bar{x}$ =3.46, 3.39	$\bar{x}$ = 3.19, 3.29	$\bar{x}$ = 3.44, 3.33	$\bar{x}$ = 3.36, 3.33
Yes(Y) = 28	m = 3.50, 3.50	m = 3.50, 3.00	m = 3.33, 3.33	m = 3.17, 3.33	m = 3.36, 3.43	s = 0.60, 0.52
No(N) = 122	Z = -0.691	Z = -2.084**	Z = -0.317	Z = -0.983	Z = -0.902	t = -0.298
Engineer	$\bar{x}$ = 3.35, 3.35	$\bar{x}$ = 3.19, 3.13	$\bar{x}$ = 3.45, 3.37	$\bar{x}$ = 3.24, 3.28	$\bar{x}$ = 3.33, 3.36	$\bar{x}$ = 3.33, 3.34
Yes(Y) = 50	m = 3.50, 3.50	m = 3.50, 3.50	m = 3.33, 3.33	m = 3.33, 3.33	m = 3.29, 3.43	s = 0.54, 0.53
No(N) = 100	Z = -0.263	Z = -0.008	Z = -0.804	Z = -0.473	Z = -0.926	t = 0.043
Teacher	$\bar{x}$ = 3.46, 3.32	$\bar{x}$ = 3.07, 3.17	$\bar{x}$ = 3.54, 3.37	$\bar{x}$ = 3.33, 3.25	$\bar{x}$ = 3.48, 3.32	$\bar{x}$ = 3.45, 3.31
Yes(Y) = 28	m = 4.00, 3.50	m = 3.50, 3.50	m = 3.67, 3.33	m = 3.67, 3.33	m = 3.57, 3.43	s = 0.47, 0.54
No(N) =122	Z = -1.369	Z = -0.228	Z = -1.389	Z = -0.749	Z = -1.637	t = -1.404
Other STEM	$\bar{x}$ = 3.44, 3.33	$\bar{x}$ = 3.12, 3.15	$\bar{x}$ = 3.24, 3.42	$\bar{x}$ = 3.20, 3.28	$\bar{x}$ = 3.45, 3.34	$\bar{x}$ = 3.22, 3.35
Yes(Y) = 17	m = 3.50, 3.50	m = 3.50, 3.50	m = 3.33, 3.67	m = 3.33, 3.33	m = 3.43, 3.43	s = 0.49, 0.54
No(N) = 133	Z = -0.110	Z = -0.122	Z = -0.594	Z = -0.999	Z = -0.706	t = 0.975
Non-Science	$\bar{x}$ = 3.4, 3.35	$\bar{x}$ = 3.27, 3.10	$\bar{x}$ = 3.39, 3.41	$\bar{x}$ = 3.37, 3.23	$\bar{x}$ = 3.36, 3.35	$\bar{x}$ = 3.36, 3.32
Yes(Y) = 45	m = 3.50, 3.50	m = 3.50, 3.50	m = 3.33, 3.67	m = 3.33, 3.33	m = 3.43, 3.43	s = 0.58, 0.51
No(N) = 105	Z = -0.858	Z = -0.799	Z = -0.873	Z = -0.913	Z = -0.169	t = -0.427

*p < 0.1, **p < 0.05, ***p < 0.001

The only statistically significant gender difference identified was with respect to science confidence, where men indicated more science confidence than women. Participants with higher degree levels reported a higher interest in science and science confidence. Underrepresented minority (URM) participants indicate a higher level of engineering interest. Engineering recognition was higher for participants who completed an engineering degree, BME or other engineering. Participants with an engineering degree other than BME indicated more engineering recognition and more science confidence than participants without another engineering degree. Finally, the influence of family occupation on identity was limited. Only participants with a scientist as a family member indicated more science recognition.

Table 5: Comparison of Means for Personal Demographics and Direct Identity Measures

	BME Perception	**Engineering Identity**	**Science Identity**	**Individual Identity Difference**
Gender: (W, M)	$\bar{x}$ = 4.24, 4.35	$\bar{x}$ = 3.28, 3.53	$\bar{x}$ = 3.26, 3.34	$\bar{x}$ = 0.01, 0.19
Women(W) = 72	s = 1.09, 1.21	m = 3.00, 4.00	m = 3.00, 4.00	s = 1.00, 1.19
Men(M) = 77	t = -0.606	Z = -2.909***	Z = -0.785	t = -1.066
Education (L,U)	$\bar{x}$ = 4.27, 4.33	$\bar{x}$ = 3.40, 3.42	$\bar{x}$ = 3.27, 3.35	$\bar{x}$ = 0.12, 0.07
Lower(L) = 88	s = 1.23, 1.05	m = 4.00, 4.00	m = 3.00, 4.00	s = 1.04, 1.22
Upper(U) = 60	t = -0.321	Z = -0.074	Z = -0.769	t = 0.303
Race (N, U)	$\bar{x}$ = 4.25, 4.53	$\bar{x}$ = 3.37, 3.43	$\bar{x}$ = 3.30, 3.31	$\bar{x}$ = 0.12, 0.07
Non-URM(N) = 115	s = 1.18, 1.04	m = 4.00, 4.00	m = 4.00, 4.00	s = 1.01, 1.48
URM(U) = 30	t = -1.308	Z = -0.209	Z = -0.255	t = 0.196
Degree Type (Y, N):				
BME	$\bar{x}$ = 4.35, 3.89	$\bar{x}$ = 3.48, 2.89	$\bar{x}$ = 3.25, 3.67	$\bar{x}$ = 0.22, -0.78
Yes(Y) = 130	s = 1.08, 1.16	m = 4.00, 3.5	m = 3.5, 4.00	s = 0.10, 1.48
No(N) = 18	t = -1.698	Z = -1.585	Z = -1.742*	t = -2.787**
Other Engineering	$\bar{x}$ = 4.48, 4.22	$\bar{x}$ = 3.63, 3.30	$\bar{x}$ = 3.22, 3.34	$\bar{x}$ = 0.41, -0.04
Yes(Y) = 46	s = 1.11, 1.17	m = 4.00, 4.00	m = 3.00, 4.00	s = 1.13, 1.08
No(N) = 102	t = -1.308	Z = 0.014**	Z = 0.315	t = -2.289**
Other Science	$\bar{x}$ = 3.60, 4.35	$\bar{x}$ = 2.40, 3.48	$\bar{x}$ = 3.9, 3.26	$\bar{x}$ = -1.50, 0.22
Yes(Y) = 10	s = 0.97, 1.16	m = 2.00, 4.00	m = 4.00, 3.00	s = 1.35, 1.00
No(N) = 138	t = 2.330**	Z = -2.935***	Z = -2.466**	t = 3.934***

*p < 0.1, **p < 0.05, ***p < 0.01

Tables 5 and 6 show differences in direct measures of identity by gender, education, race/ethnicity, degree type, and family profession. Men indicated a stronger engineering identity than women. While having a BME degree did not influence participants' perceptions of engineering or science identity, having an engineering degree other than BME or another science degree did influence engineering and science identity. Those with an engineering degree other than BME perceive a stronger engineering identity and those with another science degree other than BME perceive a stronger science identity. Individuals with either a BME or other engineering degree identified more with engineering than science, and the opposite is true for individuals with other science degrees. No other statistically significant differences were found under the $p > 0.1$ threshold.

Table 6: Differences in Direct Identity Measures by Family Profession

Profession (Y, N):	**BME Perception**	**Engineering Identity**	**Science Identity**	**Difference**
Medicine/Health	$\bar{x}$ = 4.42, 4.24	$\bar{x}$ = 3.50, 3.38	$\bar{x}$ = 3.37, 3.29	$\bar{x}$ = 0.13, 0.09
Yes(Y) = 38	s = 1.03, 1.20	m = 4.00, 4.00	m = 4.00, 3.50	s = 1.12, 1.10
No(N) = 112	t = -0.892	Z = -0.946	Z = -0.594	t = -0.202
Scientist	$\bar{x}$ = 4.21, 4.30	$\bar{x}$ = 3.54, 3.38	$\bar{x}$ = 3.46, 3.27	$\bar{x}$ = 0.07, 0.11
Yes(Y) = 28	s = 0.10, 1.19	m = 4.00, 4.00	m = 4.00, 3.00	s = 0.94, 1.14
No(N) = 122	t = 0.411	Z = -0.668	Z = -1.536	t = 0.171
Engineer	$\bar{x}$ = 4.40, 4.23	$\bar{x}$ = 3.44, 3.39	$\bar{x}$ = 3.30, 3.31	$\bar{x}$ = 0.14, 0.08
Yes(Y) = 50	s = 1.07, 1.20	m = 4.00, 4.00	m = 3.50, 4.00	s = 0.86, 1.21
No(N) = 100	t = -0.822	Z = -0.023	Z = -0.314	t = -0.350
Teacher	$\bar{x}$ = 4.50, 4.24	$\bar{x}$ = 3.61, 3.36	$\bar{x}$ = 3.21, 3.33	$\bar{x}$ = 0.39, 0.03
Yes(Y) = 28	s = 1.04, 1.18	m = 4.00, 4.00	m = 3.50, 4.00	s = 1.17, 1.08
No(N) =122	t = -1.176	Z = -1.484	Z = -0.472	t = -1.493
Other STEM	$\bar{x}$ = 4.06, 4.32	$\bar{x}$ = 3.41, 3.41	$\bar{x}$ = 3.24, 3.32	$\bar{x}$ = 0.18, 0.09
Yes(Y) = 17	s = 1.25, 1.14	m = 4.00, 4.00	m = 4.00, 4.00	s = 1.02, 1.12
No(N) = 133	t = 0.806	Z = -0.382	Z = -0.016	t = -0.326
Non-Science	$\bar{x}$ = 4.20, 4.32	$\bar{x}$ = 3.31, 3.45	$\bar{x}$ = 3.33, 3.30	$\bar{x}$ = -0.02, 0.15
Yes(Y) = 45	s = 1.01, 1.21	m = 4.00, 4.00	m = 4.00, 4.00	s = 1.23, 1.05
No(N) = 105	t = 0.645	Z = -0.701	Z = -0.237	t = 0.830

*p < 0.1, **p < 0.05, ***p < 0.01

4.4 Linear Regression Analysis

A separate linear regression was run for each dependent identity measure. The linear regression coefficients signify the change in the mean of the dependent identity variable for every unit change in the independent variable. Engineering recognition was significantly related to identifying more as an engineering than as a scientist and science recognition was significantly related to identifying more as a scientist than as an engineer. None of the other identity constructs were found to have a significant impact on engineering or science identity. However, engineering interest and engineering recognition were related to perceiving BME more as engineering than as science.

Table 6: Linear Regression Coefficients for Identity Constructs and Direct Identity Measures

	BME Perception	**Engineering Identity**	**Science Identity**	**Individual Identity Difference**
Gender	0.014	0.105	0.019	0.068
Education	0.102	-0.011	-0.024	0.010
Engineering Recognition	0.264***	0.578***	-0.031	0.479***
Science Recognition	-0.116	-0.030	0.626***	-0.514***
Engineering Interest	0.187*	0.075	-0.018	0.074
Science Interest	-0.103	0.102	0.123	-0.017
Engineering Confidence	0.089	0.057	0.055	0.002
Science Confidence	-0.118	0.088	0.094	-0.005

*p < 0.1, **p < 0.05, ***p < 0.01

5. Discussion

This paper applies the critical science agency and critical engineering agency frameworks to BME students and professionals. Results indicate that many biomedical engineers professionally identify slightly more as engineers than as scientists, but perceive BME to fall relatively evenly between science and engineering. Individuals with high scores for the engineering identity constructs, particularly recognition and interest were more likely to see BME as mostly engineering but the same was not true for the science identity constructs. This may indicate that a strong personal engineering identity influences BME students and professionals to match their view of the BME field more than strong science identity does. This could have interesting implications for those who consider themselves in the BME field but have stronger professional identities in science than engineering, especially if they have degrees in science disciplines. More research would need to be done about sense of belonging within the BME field for such individuals.

5.1 Recognition and Family Influences

Recognition was the strongest predictor of professional identity for both engineering and science. This is especially clear when analyzing professional identity on a scale of 'mostly science' to 'mostly engineering', similar to the scale given for the perception of BME.

Interestingly, occupation of family members did not show to have a significant impact on any identity measures. The only significant difference found was between having a scientist family member and increased science recognition. This contradicts previous research that suggests family influence, especially influence of parents, as an important factor in the development of interests and professional identity [18]-[20]. Other studies, however, assert that family influence is less influential than other factors, such as the presence of supportive peers, counselors, and professors at their schools and universities [21]-[23]. It is also important to note that the profession of a family member may not be entirely reflective of the influence that family member has on shaping the student's views about science and/or engineering.

5.2 Educational Background and Social Identity

Our results indicate that individuals with BME degrees have moderately strong engineering identities and are recognized similarly to those with other engineering degrees. Individuals with science degrees, on the other hand, are, perhaps not surprisingly, more likely to have weaker engineering identities, stronger science identities, and to perceive BME as mostly science. It may be possible that individuals with science degrees perceive BME as mostly science due to their own involvement in BME with a science background. Interestingly, those with an engineering degree (BME or other) did not necessarily perceive BME to be mostly engineering. This may reflect the uncertainty of cause and effect, since it is unclear from our data if perception of one's field influences their own identity or if professional identity shapes how an individual views their field [12]. Since our data was collected at a BME conference it is likely that the majority of participants identify themselves as biomedical engineers, although this was not explicitly measured in the survey.

Overall, few differences were found between demographics and any identity measures. High educational level was associated with increased science interest and confidence but had no effect on perception of BME or professional identity. This suggests that while individuals gain experimental and reasoning skills more traditionally associated with science than with engineering, many continue to identify with engineering, especially if they have earned or are pursuing an engineering degree of any sort. In alignment with previous research [24][25] and previous t-test analysis of this data [17-men reported that they saw themselves as engineers more on average than women. There was also no significant difference between race/ethnicity and any of the direct identity measures, although underrepresented minorities were more likely to report interest in engineering. Understanding how racial minorities and women perceive themselves in the context of engineering has the potential to more closely meet their educational needs and increase their retention within engineering fields [7][23].

5.3 Limitations and future work

The major limitation of this study was the survey setting and population. Survey participants represented a wide range of ages, education levels, and educational backgrounds (such as major and institution). Our sample size was small relative to the large array of identities and backgrounds of participants, rendering the sample size for certain groups, such as people with non-BME science degrees, rather small.

Furthermore, various demographics were not equally represented, especially race and degree type. Our sample population included individuals with varying education levels and participants were therefore divided into two groups based on highest current or completed degree. However, due to this grouping we did not distinguish students who were early in their degree program from those who were late in their degree program and we also grouped current students and professionals without a PhD together.

Additional limitations arose due to the content of the survey. Potentially useful data was lost in neglecting to allow participants to rate the extent to which they perceived BME to be an engineering discipline and a science discipline independently, and conversely, potentially useful data was lost by not asking participants to directly choose whether they identified themselves more as an engineer or more as a scientist. It is also important to note that our survey did not ask participants to what extent they identified with BME. For the sake of data interpretation, we assumed their status as a biomedical engineer as a result of their presence at the BME conference. Additionally, the science and engineering identity constructs could potentially be measured via different questions, especially with engineering interest and engineering confidence, to yield more reliable constructs.

Future studies can build upon this research by focusing more narrowly on a specific population, such as undergraduate students or graduate students at one institution. On the other hand, to further study the effect of degree type on identity, solely professionals who consider themselves biomedical engineers could be studied. Building off of multiple identity theories, future work can explore contexts in which students and/or professionals in BME identify or experience their identities differently, especially as it relates to identifying more as a scientist or as an engineer. Social identities beyond gender and race, such as socio-economic status, sexual orientation, and ability status, can be incorporated into a multiple identity theory framework to conduct a more robust study on the connections between social identity and professional identity for biomedical engineers. More can also be done to examine the influence of identity on persistence in BME and how identity is related to career aspirations among BME students. Finally, testing perceptions of science and engineering influence can be applied to other engineering majors, especially those which are multidisciplinary, or which commonly have stronger ties to science disciplines than traditional engineering disciplines. Such a study could reveal insights into how students view different engineering majors that could have implications for creating curriculum tailored to students' identities and perceptions of their major.

This study and previously mentioned potential related studies could become valuable tools to guide the design and implementation of BME curriculum at various levels. For instance, the results from this study suggest it may be important to ensure that students trained in BME are comfortable speaking the languages of science and engineering because in the field there is influence from both. Additionally, recognizing students as engineers, scientists, or both (within the language of a program or class, for example) may cause them to identify more as engineers and/or scientists. Another interesting finding was that BME, despite many differences from more traditional engineering disciplines, had students who identified more as engineers and were recognized more as engineers than other engineering majors. This may have interesting implications for examining how biomedical engineers are taught compared to other engineering students. Finally, our data suggests that family professions may not be an influence and is certainly not as strong of an influence as other factors, which gives hope for diversifying the field and giving opportunities to those from families without STEM professionals.

6. Conclusion

We found that BME students and professionals, on average, view BME as equally incorporating science and engineering. Perception of BME was influenced by some individual identity measures, indicating that those with stronger engineering identities may view BME as closer to engineering than science while those with backgrounds in science hold the opposite view. Three predictors of identity, recognition, interest, and confidence were strong predictors for self-reported identity in science and engineering. Of these, recognition was the most closely related to professional identity in engineering and science. Race and gender were not found to affect perception of BME, but gender was found to have a significant effect on individual engineering identity.

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Appendix – Survey Questions Analyzed in this Study

Survey Question	**Options**
Demographics	
What is your age?	18-24; 25-34; 35-44; 45-54; 55-64; 65+
What is your gender?	(fill in the blank)
Which category or categories best describes you? (may select multiple)	Asian; Black or African American; White; Hispanic/Latinx; American Indian or Alaska Native; Native Hawaiian or Pacific Islander; Middle Eastern or North African; Prefer not to answer; Other: (fill in the blank)
Family Educational Background	
Please list all current/completed degrees	(open-ended)
Are any members of your family employed in the following professions?* (Mark ALL that apply) • Medical/health professional • Scientist • Engineer • Teacher • Other science, technology, or math related career Non-science related career	Mother/Guardian 1 Father/Guardian 2 Siblings Other relative Spouse
Career Goals	
What are your current career goals?	(open-ended)
Direct Measures of Identity	
Where would you rate Biomedical Engineering on the following scale?	Likert (1-7)
Recognition/Confidence/Interest	
To what extent do you disagree or agree with the following statements.* • I see myself as an engineer** • I see myself as a scientist** • My peers see me as an engineer • My peers see me as a scientist • My relatives/friends see me as an engineer • My relatives/friends see me as a scientist	Likert (0-4)
Please rate your general interest in the following areas:* • Understanding science in everyday life • Telling others about scientific concepts • Making scientific observations • Applying scientific knowledge to engineering • Using engineering to explore scientific phenomena • Designing new procedures or devices	Likert (0-4)
How confident are you in your ability to do the following:* • Design an experiment to answer a scientific question • Conduct an experiment on your own • Interpret experimental results • Apply science knowledge to an assignment or test • Explain a science topic to someone else	Likert (0-4)
To what extent do you disagree or agree with the following:* • I hope to gain general knowledge across multiple fields • I often learn from my peers • I identify relationships between topics from different fields • I analyze projects broadly to find a solution that will have the greatest impact • I seek input from those with a different perspective from me • I seek feedback and suggestions for personal improvement • When problem solving, I focus on the relationships between issues	Likert (0-4)

**Adopted from the Sustainability and Gender in Engineering (SAGE) Survey [16]*
***Direct Measures of Identity*