INVESTIGATING THE FUTURE OF 'ENGINEER OF 2020' ATTRIBUTES: MOVING FROM ACCESS TO ENGAGEMENT & SENSE OF BELONGING

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ABSTRACT

Using data from the National Survey of Student Engagement (NSSE), this study seeks to explore the presence and relevance of NAE's 'Engineer of 2020' competencies and key student learning outcomes (SLOs) among samples of undergraduate engineering majors (UEMs). Data were analysed using a battery of statistical tests assessing UEMs achievement of NAE SLOs, the extent to which SLO achievement in NAE domains influence UEMs' key outcomes (e.g., grades, satisfaction) and sense of belonging. Follow-up tests explored meaningful differences among groups by race, gender, disability status, to name a few. Implications for future engineering education policy, practice, pedagogy and research are highlighted.

KEYWORDS

Science, technology, engineering, math (STEM); sense of belonging; engagement; race/ethnicity

1. INTRODUCTION

It may be hard to believe, but it has been almost 20 years since the National Academy of Engineering (NAE) published The Engineer of 2020: Visions of Engineering in the New Century [1]. That report cast a vision for the future of engineering by exploring questions about the profession, how it would be impacted by technology, and how such changes could potentially influence engineering policy, practice, and pedagogies. Five guiding principles that informed development of the report were presumed to be likely powerful drivers of engineering's future. They include:

- The pace of technological innovation will continue to be rapid (most likely accelerating);
- The world in which technology will be deployed will be intensely globally interconnected;
- The population of individuals who are involved with or affected by technology (e.g., designers, manufacturers, distributors, users) will be increasingly diverse and multidisciplinary;
- Social, cultural, political, and economic forces will continue to shape and affect the success of technological innovation;
- The presence of technology in our everyday lives will be seamless, transparent, and more significant than ever.

Applying these principles to engineering education led to identification of critical learning objectives or student learning outcomes (SLOs) that educators and employers *desired* and could

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reasonably expect of future engineering graduates. These SLOs include without limitation: critical thinking, creativity, innovation, problem-solving, use of technology, global awareness, and an appreciation for diversity that enables them to work with people whose backgrounds differ from their own [1]. Though NAE's prescient report is almost two decades old, the information contained within was posited by study authors to be relevant for the "new century" that may span well beyond 2020 into 2030 and beyond. Achievement of NAE SLOs was hypothesized to increase engineering self-efficacy, college satisfaction, and the extent to which students' felt part of undergraduate engineering education (UEE) and the profession at-large, often referred to as sense of belonging (SOB) in the existing literature [2,3].

Sense of belonging definitions abound. Generally, sense of belonging refers to a *feeling* that one *matters*, is accepted, and included in a group or community, without pressure to assimilate, change, deny, or conceal authentic aspects of themselves [2]. Belonging is one of our most basic human needs and, as I argue elsewhere [2], a human right. When people feel like they belong, they are more motivated, engaged, energized, and happier in life. In specific contexts where some are prone to feeling isolated, alienated, or marginalized such as underrepresented racial/ethnic minorities (UREMs) in STEM fields, belonging assumes greater importance in terms of learning and engagement outcomes [2,3].

Past research and scholarship on SOB in STEM fields can be organized into three major bins of knowledge. First, one line of inquiry consistently shows that sense of belonging is essential for human functioning. Belongingness needs are fulfilled by quality relationships or social bonds with others that are positive and frequent. Satisfaction of interpersonal relationships (e.g., friendships, mentoring) must be accompanied by a conviction and sense that the relationship bond is caring, safe, secure, mutual, authentic, and reasonably lasting [5].

Another line of inquiry provides evidence documenting the fact that sense of belonging assumes heightened importance in contexts where individuals are more prone to stereotype threat, marginalization, and invisibility such as women and people of color in STEM [2]. This category also includes studies demonstrating the negative consequences that result when sense of belonging needs are not met such as depression, conflict, and loneliness [6], as well hijacked concentration [7].

Studies that investigate major contributors to sense of belonging generally, and in UEE specifically, represent a third category. Chief among these are core traits and personal characteristics such as gender identity, race/ethnicity, and even the nature of STEM learning environments that tend to be predominantly white, normative, and male dominated. For instance, Wilson and VanAnwerp conducted a systematic review of literature using Templar and Pare's approach. That design yielded 544 articles from which 36 eligible studies emerged. They found evidence supporting the fact that sense of belonging results in feelings of inclusion and support. They also highlighted that women feel adequate sense of belonging in engineering, though less belonging relative to men with several other studies showing no gender differences [3].

While useful for (re)envisioning the future of engineering and delineating core SLOs for UEE, more empirical information is needed that examines the (a) presence/relevance of NAE's SLOs in UEE today, (b) achievement of NAE's SLOs among UEMs at 4-year public and private universities in the United States (US) including any group differences, and (c) extent to which UEMs' achievement of NAE SLOs influences their SOB in college or academic major. These are the gaps addressed by the study that informs this EDU 2023 paper.

2. RESEARCH QUESTIONS

Three primary research questions guide the quantitative investigation that informs this project. Using large-scale, nationally representative data from the National Survey of Student Engagement (NSSE), the study's research questions include:

1. What is the frequency and nature of UEMs engagement in high-impact practices (HIPs), as identified by the NSSE, and the extent to which they perceive growth and learning in the NAE's SLOs domains (e.g., critical thinking, diversity)?
2. To what extent, if any, are NAE's SLOs achieved (in)equitably among UEMs, paying attention to potential differences by gender, race/ethnicity, engineering subfield, and enrollment status, to name a few?
3. What is the relationship between UEMs' achievement of NAE SLOs and their overall SOB in college or academic major, controlling for confounding factors?

3. THE STUDY

The present study employed an ex-post facto survey design to assess the extent to which NAE SLOs identified in The Engineer of 2020 report can be operationalized in existing recent NSSE data from UEMs. An ex-post facto survey design is a type of method that involves collecting and analyzing data after a study or experience has taken place. In that way, it usually involves existing databases, public records, or interviews eliciting perceptual, behavioral, and self-report data offering insights into phenomena not previously understood (Goodman-Scott et al., 2021).

3.1. Data Sources and Sample

In light of the study's objectives and research questions, data were drawn from a national administration of NSSE across over 700 colleges and universities to assess UEMs' engagement in HIPs, achievement of SLOs, and group-based differences, using a sample exceeding 28,000 STEM majors. This database allowed exploration and investigation of specific campus-based science, technology, engineering, math (STEM) or UEE practices, pedagogies, and/or interventions believed to be related to NAE's SLOs that were tapped by NSSE.

The study sample consisted of 121,293 college students who responded to the NSSE. Given the study's focus, the analytic sample was comprised of 28,211 STEM majors, defined as biological and physical sciences, engineering, math, as well as computer science and technology. In keeping with NSF practices, health and allied fields, social sciences, education, and "undeclared" were excluded from STEM classifications. Most (92%) were enrolled full-time, 10% had been "diagnosed with *any* disability/impairment," and 60% identified as heterosexual/straight. Half were women and just under half identified as "man," leaving less than 2% as "another gender identity" or prefer not to respond. The majority were traditionally aged (45% 19 and younger; 40% 20 to 23 years), 7% student-athletes, 4% military veterans, and 4% were international students. In terms of race/ethnicity, 46% were white, 15% Hispanic/Latino, 15% multiracial, 11% Black/African American, and 8% Asian Pacific Islander, with less than 1% American Indian/Alaskan Native.

Largely reflecting the complexion of student respondents, NSSE-participating institutions within the sample were varied and diverse. 27% of sample respondents attended doctoral/research-extensive (highest activity) institutions, where 9% attended liberal arts, baccalaureate colleges. Nearly three-quarters (72%) attended public institutions, with over half (52%) at very large (10,000 or more students), 30% at medium-to-large (2,500 to 9,999), and 15% at small

institutions with less than 2,500 students. Approximately 3% of the sample attended historically Black colleges and universities (HBCUs), whereas 12% attended Hispanic-serving institutions (HSIs).

3.2. Data Analysis

Data were analyzed using a battery of statistical tests. Descriptive statistics were computed to report the frequency and nature of students' engagement in HIPs and achievement of SLOs. Bivariate correlations (not presented herein) assessed the direction and magnitude of interrelationships among key variables. Tests for group mean differences (i.e., t-tests, ANOVA) were used to evaluate differences in outcomes among independent samples (e.g., men vs. women). Lastly, hierarchical regression tests, with statistical controls, were used to answer the third research question. Preliminary analysis of full sample data indicated that less than 2% of cases were missing on key variables, with missingness ranging from 0 to 1.1%.

4. RESULTS

WHAT IS THE FREQUENCY AND NATURE OF UEMS ENGAGEMENT IN HIPS AND PERCEIVED GROWTH AND LEARNING IN NAE SLO DOMAINS?

Results provide persuasive evidence of UEMs engagement in HIPs and educationally purposeful learning experiences as delineated by NAE. For example, over half (53%) of STEM majors in this study *planned* to do an "internship, co-op, field experience or clinical placement" and over one-third (31%) had already done so, at the time of data collection. Over one-quarter (25%) *planned* to hold a formal leadership role in a student group, whereas 28% had done so or were "in progress." Although only 9% had studied abroad, another 25% *planned* to do so. And likely reflective of the nature of UEE cultures, 24% had worked with faculty on a research project and 32% *planned* to do so. Table 1 presents a summary.

[Table 1 about here]

Perceived growth and learning in NAE SLO domains was assessed using descriptive statistics on relevant survey items, each placed on a 4-point Likert-type scale ranging from 1 ("very little") to 4 ("very much"). To this end, 17 survey items were analyzed and interpreted. Areas of greatest perceived growth and learning include purposeful discussions with diverse others whose *race/ethnicity* (M=3.10, SD=0.92) or *economic background* (M=3.07, SD=0.88) differs from one's own; *thinking critically and analytically* (M=3.23, SD=0.80) and *analyzing numerical/statistical information* (M=3.09, SD=0.87). Areas of least perceived growth and learning include *using numerical information to solve real-world problem* (M=2.43, SD=0.96), *evaluating others' conclusions* (M=2.52, SD=0.90), and *being/becoming an informed citizen* (M=2.57, SD=0.97). Table 2 presents a summary, noting differences between STEM and non-STEM majors.

[Table 2 about here]

TO WHAT EXTENT, IF ANY, ARE THERE GROUP DIFFERENCES IN NAE SLO ACHIEVEMENT?

Independent-samples *t*-tests were conducted to analyze group-based differences in NAE SLOs. Several group differences emerged in terms of sexual orientation. Statistically significant group differences were found for 10 NAE SLOs, plus sense of belonging: *evaluated others conclusions* from numerical information, writing clearly and effectively, speaking clearly and effectively,

thinking critically and analytically, analyzing numerical statistical information, acquiring job/work-related skills, working effectively with others, developing or clarifying personal values and ethics, understanding diverse people, solving complex world problems, and sense of belonging. Generally, higher gains were reported by heterosexual/straight STEM majors compared to LGBTQIA+ students. Table 3 presents a summary.

[Table 3 about here]

A separate analysis using independent-samples *t*-test was conducted to evaluate the hypothesis that group means on NAE SLOs were lower for first-generation (FG) compared to continuing (non-FG) generation STEM majors. Several tests were significant in the hypothesized direction including 10 NAE SLOs and sense of belonging: *reached conclusions based on numerical analysis* (t[23630.1]=-6.72, p<0.001), *evaluated others conclusions* (t[27957]=-5.86, p<0.001), *writing clearly and effectively* (t[24162.54]=8.67, p<0.001), *speaking clearly and effectively* (t[24147.33]=8.93, p<0.001), *analyzing statistical information* (t[27987]=-3.58,p<0.001), *acquiring job/work-related skills* (t[23442.77]=-5.19, p<0.001), *developing or clarifying personal values and ethics* (t[23970.66]=4.44, p< 0.001), *understanding diverse people* (t[28003]=7.50, p<0.001), *solving complex world problems* (t[23319.38]=-2.76, p<0.01, *being an informed citizen* (t[23351.04]=3.77, p<0.001), and *sense of belonging* (t[27937]=-9.24, p<0.001).
A final analysis using independent-samples *t*-test was conducted to evaluate the hypothesis that group means on NAE SLOs were higher for men compared to women STEM majors. Several tests were significant in the hypothesized direction including 13 NAE SLOs. For instance, *being an informed citizen* t[28027.81]=-7.18, p<0.001), *solving real-world problems* (t[28110]=5.00, p< 0.001), *working effectively with others* (t[28117.88]=-3.91, p<0.001), and *speaking clearly and effectively* (t[28114]=-4.78, p<0.001). Generally, results were in the expected direction with few exceptions such as *writing clearly and effectively* (M_w=2.81, SD_w=0.91; M_m=2.76, SD_m=0.89) and *understanding diverse people* (M_w=2.75, SD_w=0.96; M_m=2.63, SD_m=0.98).

WHAT'S THE RELATIONSHIP BETWEEN UEMS' NAE SLO ACHIEVEMENT AND SENSE OF BELONGING IN COLLEGE?

Hierarchical linear regression tests were conducted to examine the relationship between NAE SLOs and STEM majors' sense of belonging in college, controlling for an extensive array of confounding factors (e.g., gender, FG status). The regression equation was statistically significant, F(16,17916)=397.19, p<0.001, R=0.51, adjusted R^2=0.261. The NAE SLO measures predicted STEM majors sense of belonging in college over and above background factors, R^2 change = 0.257, (F13,17916)=480.70, p<0.001. Based on these results, 9 NAE SLOs were statistically significant predictors of STEM majors' sense of belonging in college, offering almost 25% more predictive power to the regression equation beyond that contributed by background factors (e.g., sex, FG status) alone. Table 4 presents a summary.

[Table 4 about here]

5. DISCUSSION

Recall the purpose of this study calls attention to the relationship between NAE SLOs and sense of belonging for STEM majors generally and UEE graduates specifically. NAE SLOs include professional skills such as speaking clearly, thinking analytically, writing effectively, and clarifying personal values and ethics, to name a few.Using large, representative NSSE data, I analyzed STEM majors' responses using both descriptive statistics and multivariate statistical tests, examining differences in responses by various identity groups, such as gender, sexual

orientation, and first-generation status, as well as hierarchical predictive models. Results indicated statistically significant differences in achievement of NAE SLOs, albeit perceived or self-reported, and students' sense of belonging in college. For example, women tended to report lower gains in STEM and UEE than men. Similar trends were uncovered for LGBTQIA+ majors compared to heterosexual students and non-FG compared to FG majors. These findings suggest curious trends and patterns that deserve further investigation as they may indicate that certain pedagogical practices, policies, and environments have a differential impact on students depending on their identity or group membership. Findings also point to obvious areas of inequities in both achievement of NAE SLOs and students' sense of belonging.

Results of this study have important implications for efforts to promote inclusive STEM education. Our findings suggest that there are significant differences in how students from different identity groups perceive achievement or attainment of NAE SLOs and their sense of belonging in college. This highlights the need for targeted interventions to address these disparities and improve outcomes for all students. For example, STEM and UEE departments may do well to develop new or expand existing pathway programs for women, LGBTQIA+, and/or FG students that provide supplemental opportunities to learn in NAE domains and ease students' transitions to academic majors that are still predominantly white, male, and normative.
Not only does the study's results imply the importance of intervention programs, but they may also point to the content and curriculum of such supports. For example, interventions could include targeted support for women in developing teamwork and collaboration skills, analyzing statistical information, and/or clarifying personal values to promote ethical decision-making among LGBTQIA+ students. Study results also seem to affirm the importance of ensuring that first-generation students have access to strong supportive social capital networks and knowledgeable individuals (e.g., mentors) who can help them navigate STEM and UEE environments, make academic choices, and become informed citizens and professionals. By addressing these areas, we can create a more equitable and inclusive STEM education system that better serves all students.

It is important to note that the present study has limitations, similar to all others. The sample is based on student respondents to the NSSE, which is a fairly expensive, fee-based instrument administered annually. Consequently, the sample may not be fully representative of all STEM education contexts, especially not small, private, liberal arts, and low-resource institutions that cannot afford participation. Additionally, the NSSE instrument relies on self-reported perceptions, which may not accurately reflect actual behaviors or experiences, although there is authoritative support for the accuracy and validity of self-report measures [8]. Future research could build on these findings by using more objective measures of student outcomes and exploring additional identity groups.

6. CONCLUSION

Overall, our study provides important insights into the relationship between NAE SLOs and sense of belonging in STEM education, and underscores the need for ongoing research and interventions to create a more inclusive and equitable STEM and UEE system in 2030 and beyond.

6.1. Figures and Tables

Table 1. Descriptive Statistics of STEM Majors' High-Impact Practices

High Impact Practice	**% "Done/In-Progress"**	**% "Plan to Do"**
Internship, co-op, field experience, student teaching, clinical placement	31%	53%
Formal leadership in student organization	28%	25%
Learning community[1]	20%	18%
Study abroad program	9%	25%
Worked with faculty on research	24%	32%
Culminating senior experience[2]	26%	43%
Service learning course(s)[3]	48%	50%

[1]Learning community also includes "other formal program(s)" where groups of students take two or more classes together, but does not necessarily imply same/similar living arrangement
[2]Culminating senior experience includes capstone course, senior project, thesis, comprehensive exam, portfolio
[3]Service learning course responses differed from other items with ratings ranging from 1 (none) to some, most, and all.
Note. Percentages may not total 100, due to rounding.

Table 2. Descriptive Statistics of NAE SLOs

NSSE Survey Item/ NAE SLO	**STEM M/SD**	**NON-STEM M/SD**
Reached conclusions based on own analysis	2.89/0.85	2.50/0.91
Used numerical information to solve real-world problem	2.43/0.96	2.32/0.93
Evaluated others' conclusions from numerical information	2.52/0.90	2.30/0.90
Writing clearly and effectively	2.78/0.90	3.02/0.86
Speaking clearly and effectively	2.69/0.94	2.91/0.91
Thinking clearly and analytically	3.23/0.80	3.23/0.79
Analyzing numerical/statistical information	3.09/0.87	2.66/0.97
Acquiring job- or work-related skills	2.71/0.97	2.83/0.97
Working effectively with others	2.93/0.88	3.01/0.88
Developing or clarifying personal values and ethics	2.69/0.98	2.90/0.95
Understanding people of other backgrounds	2.69/0.97	2.92/0.93
Solving complex real-world problems	2.76/0.94	2.78/0.95
Being an informed and active citizen	2.57/0.97	2.79/0.95
Sense of belonging in college	3.19/0.71	3.26/0.71

Note. Group difference tests indicated statistically significant differences for each item, with F values ranging from 2.47 to 1841.56, t's ranging from -0.72 to 67.11, and p's < 0.01. *Cohen's d* effect sizes range from 0.71 to 0.96, using the pooled SD.

Table 3. Group mean comparisons on NAE SLOS among STEM Majors, by Sexual Orientation.

NAE SLO	**Heterosexual/Straight M/SD**	**LGBTQIA+ M/SD**	**Combined Group Mean Difference**
Evaluated others' conclusions from numerical information	2.50/0.89	2.55/0.90	$t(18701)=2.08$, $p< 0.05$
Writing clearly and effectively	2.80/0.89	2.68/0.92	$t(2444.7)=-5.26$, $p< 0.001$
Speaking clearly and effectively	2.71/0.93	2.55/0.96	$t(2450.3)=-7.46$, $p<0.001$
Thinking clearly and analytically	3.24/0.78	3.13/0.86	$t(2393.5)=-5.20$, $p<0.001$
Analyzing numerical statistical information	3.11/0.86	3.04/0.90	$t(18734)=-3.59$, $p<0.001$
Acquiring job/work-related skills	2.73/0.96	2.61/1.00	$t(2443.12)=-4.83$, $p<0.001$
Working effectively with others	2.96/0.87	2.82/0.90	$t(2452.87)=-6.70$, $p<0.001$
Developing or clarifying personal values and ethics	2.73/0.96	2.59/0.98	$t(2459.74)=-6.16$, $p<0.001$
Understanding diverse people	2.73/0.97	2.68/0.99	$t(2454.21)=-2.11$, $p<0.05$
Solving complex world problems	2.77/0.94	2.66/0.94	$t(18734)=-4.98$, $p<0.001$
Sense of belonging	3.20/0.71	3.12/0.73	$t(18676)==4.78$, $p<0.001$

Table 4. Hierarchical Linear Regression Results Predicting STEM Majors' Sense of Belonging.

Predictor	***Unstd. B***	***SE***	***β***	***t***
Constant	1.685	0.024		6.26
Sexual orientation	-0.029	0.015	-0.013	-1.952*
FG status	-0.081	0.009	-0.056	-8.666***
Gender	-0.009	0.009	-0.006	-0.960
Reached conclusions	0.021	0.007	0.025	3.077**
Used numerical information	-0.037	0.007	-0.049	-5.618***
Evaluated others conclusions	-0.004	0.007	-0.005	-0.556
Writing clearly and effectively	0.064	0.007	0.080	8.95***
Speaking clearly and effectively	0.001	0.007	0.001	0.141
Thinking critically and analytically	0.149	0.009	0.167	17.43***
Analyzing numerical and statistical information	0.012	0.008	0.015	1.64
Acquiring job/work related skills	0.081	0.006	0.110	13.02***
Working effectively with others	0.064	0.008	0.078	8.34***
Developing or clarifying personal values and ethics	0.042	0.007	0.057	5.79***
Understanding diverse people	0.011	0.007	0.015	1.55
Solving real-world problems	0.045	0.007	0.059	6.156***
Being an informed citizen	0.082	0.007	0.112	11.93***

Note. FG = first-generation. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

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