Reaching Out to the Masses: Building Literacy About Engineering Amongst Non-Engineering Students

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Engineering literacy gained initial prominence in the 1990s in K-12 education research. Post-secondary education has had relatively little to do with this term until the past decade, where the trends have conjoined. One notable researcher who spans these decades is John Heywood, whose "Engineering literacy for non-engineers K-12" argues that the non-engineering public must come to appreciate the potential and the limitations of engineering, to situate that understanding within some ethical framework.[1] He extends this work into a more-detailed explication of engineering literacy, worth replicating in whole:

> Engineering literacy requires that we understand how individual's [sic], organizations and society interact with technology, and this requires an appreciation of the values we bring to that understanding.[...] Its contribution to liberal education would be to give an insight into the way of thinking of engineers in order to enable judgments to be made about the value of projects and the risks associated with them. [2]

This definition is problematic, though, in that it fails to produce an actual definition. Instead, it provides researchers with some ideas as to how to identify and assess engineering literacy, explicating what the research "requires that we understand."

Engineering literacy works to describe an informed citizenry, wherein the person functions effectively in a society that values engineering, as separate from technology. The National Assessment Governing Board (NAGB) defines engineering literacy more specifically:

> Engineering literacy is the ability to solve problems and accomplish goals by applying the engineering design process—a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants. Students who are able to apply the engineering design process to new situations know how to define a solvable problem, to generate and test potential solutions, and to modify the design by making tradeoffs among multiple considerations (e.g. functional, ethical, economic, aesthetic) in order to reach an optimal solution. Engineering literacy also involves recognition of the mutually supportive relationship between science and engineering. That is, engineers respond to the interests and needs of society and in turn affect society and the environment by bringing about technological change.[3]

This extensive definition touches on the many parts of engineering literacy that are most important. That is, it concerns problems and solutions, a key aspect to engineering. It is also socially oriented, especially as technologies become increasingly significant to the wider culture.

But the NAGB definition lacks an important component that we intend to include. NAGB focuses on engineers and engineering students. While this demographic certainly requires engineering literacy, their training in broad general engineering courses already includes engineering literacy. Where does this leave those who are not engineers by trade? Engineering literacy, to borrow liberally the language of Garmire and Pearson, is a general understanding of engineering.[4] It is not a comprehensive understanding, but it allows a person to function effectively in a society dependent on engineers and adept to engineering changes. Engineering literacy provides people with the tools needed in order to participate intelligently in the world around them, making good, informed citizens.

What does engineering literacy look like? Its characteristics might fall under three high-concept categories, under which fall several specific attributes pertinent to engineering literacy. Engineering literacy exists within a framework similar to the other fields that make up STEM. Yoojung Chae, Senay Purzer, and Monica Cardella, in “Core Concepts for Engineering Literacy: The Interrelationships among STEM Disciplines,” address definitions of engineering literacy inspired by standards of scientific literacy, technological literacy, and mathematical literacy.[5] Their work to find an engineering literacy (thus rounding out STEM) works off of those standards, identifying core concepts for engineering literacy. They are the abilities to

- discuss, critique, and make decisions about national, local, and personal issues that involve engineering solutions;
- understand and explain how basic societal needs (e.g., water, food, and energy) are processed, produced, and transported;
- solve basic problems faced in everyday life by employing concepts and models of science, technology, and mathematics. [5]

By looking to other standards in finding defining terms, concepts, and attributes, engineering literacy can become aligned with and integral to strengthening the cohesiveness of STEM literacy.

Garmire and Pearson identify knowledge, ways of thinking and acting, and capabilities as the three wide categories that house the attributes of engineering literacy.[4] Krupczak and Disney place these cognitive dimensions in four content realms in developing assessments for technological literacy: 1)Technology & Society, 2) Design, 3) Products & Systems, and 4) Characteristics, Core Concepts, & Connections.[6] Instead of “Technology & Society,” we could easily explore “Engineering & Society;” the acknowledgement that STEM fields interact with society, both as an agent of change and as a changed entity, is the important factor, here. The attributes of literacy are the three cognitive dimensions, which then are evaluated under the content areas. The content areas can change—and almost certainly do under different literacies—but the dimensions, the attributes, should not here change.

Methods

Extrapolating characteristics of engineering literacy from existing literature, we constructed the Engineering Literacy survey (see Survey Design section and Appendix A) to provide an instrument to determine student perceptions of their knowledge, skills, and valuing of engineering. The survey was designed to address several questions: (a) What are students’ levels of engineering literacy, in general? (b) Do students from science backgrounds differ from students with liberal arts backgrounds with respect to engineering literacy? (c) Do male and female students differ on their engineering literacy perceptions? (d) Do more advanced students (e.g., juniors and seniors) differ from less experienced students (e.g., first year and sophomore) with regard to engineering literacy?

While we anticipated that engineers would score higher in engineering literacy than non-engineers, we included them in this study as a comparative tool. A sample of students that includes engineers is representative of the campus as a while. Comparing this inclusive sample against a sample that excludes engineers can demonstrate the gap that exists between engineers and non-engineers, a conversation that we believe is worth having.

Survey Design

Following the completion of the literature review, an engineering literacy survey was developed in order to determine and individual's understanding of basic engineering ideas concepts and skills. The engineering literacy literature review identified three basic areas of interest: knowledge of basic engineering ideas and concepts, thinking and acting like an engineer, and basic skills and basic technology and mathematics. These three over arching engineering literacy ideas were then further developed in order to extract general ideas from the literature review.

These general ideas were then refined into core ideas. These core ideas were then used to construct an initial set of 21 survey items (see Appendix A), such that seven items were identified for each of the three main engineering literacy areas (i.e., engineering knowledge, engineering thinking/acting, and basic technology/mathematics skills). This initial engineering literacy survey was then psychometrically examined.

Pilot Study

The participants for the analysis of the initial engineering literacy survey included 166 undergraduate students (94 males and 72 females) with the mean age of 20.2 years (1.18 SD) from a large research university in the southeastern United States. Participants included 105 freshman, 10 sophomore, 30 juniors, 14 seniors, and 16 "other." The ethnicity of the participants included 59 Caucasian/White students, 45 African American/Black students, 28 Asian students, 31 Hispanic students, 1 Alaskan Native/American Indian student, and 2 students that listed their ethnicity as "other." All participants were enrolled in an introductory science course, were recruited via an email sent to all students enrolled in the course (256 students; response rate = 65%), participated voluntarily, and received no course credit for participation.

The central question to be addressed is whether the 3 areas, consisting of 7 items each, constitute reliable factors within the survey (see Appendix B). A first analysis determined that internal consistency (Cronbach's alpha) across the 21 items was sufficient, $\alpha = .93$. All criteria validating the use of factor analysis were satisfied: adequate sample size, Kaiser-Meyer-Olkin (KMO) sampling adequacy of .90, and Bartlett's test of sphericity was significant, χ^2 (210) = 2534.57, $p < .01$; thus, a factor analysis was conducted using the Maximum Likelihood extraction method with the Promax with Kaiser Normalization rotation method ($\kappa = 4$) on the 21 items to determine if they comprise the three areas of engineering literacy identified through the literature review. The number of factors retained was initially determined through a scree test and eigenvalues greater than 1, resulting in 4 factors explaining 70.4% of the variance. To verify this conclusion, three factor analyses were conducted setting the number of factors to extract to 3, 4, and 5; however, only one factor analysis (4 factors) met all of the necessary criteria of loadings above

.40, no crossloaded items, no factors with fewer than three items, and interpretable factor item clusters (see Table 1).[7, 8]

The four factors that emerged from the analysis, supported by component and item correlations, were *Knowledge*, *Impact*, *Thinking and Acting*, and *Skills*.

The first factor, *Knowledge*, is comprised of three items that focus on basic engineering knowledge and what engineers do for a living to a level that would allow the individual to converse intelligently with an engineer about engineering related topics.

The clearest attribute of the engineering literate person is a knowledge of engineering. He or she must recognize that engineering pervades everyday life. It is more than buildings, electronics, and systems; it is an inescapable factor of living in a culture that values and celebrates engineering accomplishments. He or she also understands basic engineering concepts and terms, such as systems, constraints, and trade-offs. This knowledge need not be nuanced or in-depth; a familiarity with terms, for purposes of conversing with engineers, or of understanding some principles of engineering, would likely suffice. This knowledge also includes a familiarity with the nature and limitations of the engineering design process, for many of the same reasons and purposes. This factor was labeled "Basic Knowledge of Engineering and Engineers."

Table 1. Component Loadings (Pattern Matrix) for 21 Items[*]

	Components			
	1 Knowledge	**2 Impact**	**3 Think/Act**	**4 Skills**
1. I understand basic engineering terms	.868			
2. I understand what an engineer does	.885	.131		
3. I understand basics of design process	.769	.315	-.121	
4. I see the impact of engineering	.294	.439	.237	
5. I see engineering's impact on society	.234	.724		
6. I see society's impact on engineering	.258	.649		.167
7. I understand engineering risks	.103	.860		
8. I consider benefits/risk or action	-.194		.844	.128
9. I learn new technologies			.574	.213
10. I believe non-engineers contribute	.235		.443	.201
11. I identify problems to be solved	.169	.170	.715	-.100
12. I think about multiple perspectives	-.220		1.019	
13. I take into account cultural views	.250		.750	
14. I believe in acting ethically	.162	-.271	.604	.144
15. I use basic technologies effectively		.214		.681
16. I use web technologies effectively	.196	-.208	-.112	.876
17. I use word processors effectively	.225	-.269		.803
18. I use presentation apps effectively	.199	-.323		.768
19. I use math skills effectively	-.156	.205		.789
20. I learn new technologies effectively	-.332	.276		.910
21. I like to learn new technologies		.300		.663
Eigenvalues	1.40	1.02	2.55	9.80
% of Total Variance	6.70	4.86	12.14	46.68
Cronbach's Alpha	.90	.82	.89	.91
Number of items	3	4	7	7

*Loadings => .10

The second factor, *Impact*, is comprised of four items that focus on the reciprocal relationship between engineering and culture. Specifically, this factor addresses how engineering has impacted humanity, while humanity has also impacted engineering.

Social aspects of engineering literacy also surface here. A knowledge of some ways in which engineering has shaped human history and people have shaped engineering are of clear importance, as engineers, too, have the ability to shape history and culture similarly. An awareness of the mutual impact of engineering and society is useful both for engineers and non-engineers. Similarly, engineering literacy includes an understanding that all engineering projects entail risk—a risk that cannot always be anticipated. Perhaps most importantly, this citizen understands that engineering is not an a-political investment, and that not all engineers are disinterested. Engineering reflects the values and culture of society, and the engineer is not immune to his or her cultural situation.

The history and evolution of engineering is another foray into the relationships between society and engineering. Looking at the change of engineering over time is valuable, as it showcases the development of certain social aspects of engineering. Perhaps engineering historians explore the development and transformation of engineering as a profession, or perhaps they develop a comparative study of a variety of engineering cultures.

Studying different disciplines of engineering and technology is another avenue that can inform relationships between technology and society. Bijker and Pinch developed a sociology of technology that has become known as the Social Construction of Technology.[9] They argue that users and producers of technology, and by extension engineering, are the most basic groups when it comes to the acceptance or rejection of a particular technology. This sociologically-charged view of technology and engineering makes explicit connections between the disciplines of sociology and engineering.

The integration of engineering in society requires some bigger ideas in order to be effective. Ethics are important in engineering literacy, as both engineers and non-engineers are expected to behave professionally responsibly. This content area combines philosophy and engineering studies in a very practical way, contributing to conceptualizations of ways to approach appropriate decision-making. This factor was labeled, "Impacts of Engineering on Human Life."

The third factor, *Thinking & Acting*, is comprised of seven items that focus on the ability to think (e.g., benefit/risk analysis, problem solving, cultural sensitivities) and act (e.g., ethically, problem identification, learn new technologies) in ways similar to engineers.

What, then, does engineering literacy teach? Garmire and Pearson identify it as "ways of acting and thinking," or processes that an engineering-literate citizen learns and practices regularly.[4] He or she asks pertinent questions, of self and others, regarding the benefits and risks of engineering. This citizen also seeks information about new technologies and new engineering projects. The thirst for knowledge is important, especially as technological endeavors, including engineering projects, can change dramatically and quickly.

Engineering literacy also teaches citizens to participate when appropriate and available in decisions about the development and use of engineering technologies. This is not available to all citizens, but an informed and invested citizenry makes engineering literacy meaningful and widely visible. An investment outside the world of engineers makes informed citizens valuable to engineering projects, and it allows engineers to see the impact of their work in the wider world.

At its core, engineering is about defining problems and solutions, as suggested by Dominique Vinck.[10] Learning how engineers identify problems and valid solutions differently across cultures is valuable on its own. Figuring out how to work with those who solve problems differently is valuable, too, and not just for engineers. It is a skill that has become increasingly important as global connections become clearer. And it does not relate solely to international cultures, but cultural expectations within the same culture, though across generations and with various subcultures that impact how a person acts in and sees the world.

Engineers often learn how to develop and enhance a systems way of thinking. Understanding this method of decision-making may prove useful in developing an engineering literacy, as a way of learning how engineers think. By understanding the complexity of the world, the web of relationships, long-term causes and effects, social consequences, and more, engineering-literate persons can further understand habits of systems thinkers, such as changing perspectives, testing assumptions, considering all aspects of an issue, and recognizing structure and change.[11] This factor was labeled, "Thinking and Acting Like an Engineer."

The fourth factor, *Skills*, is comprised of seven items that focus on the ability to learn and use basic technologies (e.g., productivity software, web applications, new technologies).

The final attribute of engineering literacy, skills, may tread closely to knowledge. Engineering literacy must instruct, to some degree, some of the utility of engineering that might be practiced by non-engineers.

The engineering-literate have some range of hands-on skills, which can include using a computer for word processing and online searching, operating several variety of home and office appliances, and understanding, or demonstration of effort to understand, how some household accessories work. Furthermore, he or she can identify and fix simple mechanical or technological problems at home or work. Expertise is not a requirement of engineering literacy. Application of basic mathematical concepts related to probability, scale, and estimation help make informed judgments about the risks and benefits of engineering endeavors.

Most broadly, capabilities can be applied within the context of a specified, cross-cutting content area.[12] Exploring the actual and potential abilities of engineers relates to knowledge of engineering, but it also relates to decision-making. Decisions rely on capabilities, as one cannot decide to take an impossible (i.e. incapable) action. This factor was labeled, "Basic Skills in the Use of Technologies."

Overall, the principal component analysis with Promax rotation yielded four strong factors. These factors aligned well with the concepts emerging from the literature reviews.[1, 2, 6] Upon completion of the pilot study, an additional question emerged: With a larger sample size, are the survey's psychometrics still appropriate? We conducted a larger study with an expanded sample.

Expanded Study

Student perceptions of engineering literacy were examined using a web-based survey. The survey was sent out to a large geography course (2403 students) that was part of the university's Curriculum for Liberal Education (core curriculum/general education curriculum). Participating students were provided three days to complete the survey prior to a reminder email being sent. Following another 3 days, the survey was taken off line.

The participants for the survey included 1753 undergraduate students (1049 males and 677 females, 27 did not respond) with the mean age of 19.4 years (1.02 SD) from a large research university in the southeastern United States. Participants included 1183 freshman, 66 sophomores, 362 juniors, 56 seniors, and 86 no response. The ethnicity of the participants included 509 Caucasian/White students, 91 African American/Black students, 313 Asian students, 243 Hispanic students, 10 Alaskan Native/American Indian student, and 17 students that listed their ethnicity as "other." Finally, there were 661 students from the College of Engineering (CoE), 363 from the College of Business (CoB), 252 from the College of Science (CoS), 195 from the College of Liberal Arts and Human Sciences (CLAHS), 109 from the College of Agriculture and Life Science (CALS), 90 from the College of Architecture and Urban Studies (CAUS), 39 from the College of Natural Resources and Environment (CNRE), 2 from the School of Medicine (SoM), and 2 from the Graduate School (Grad). All participants were enrolled in an introductory geography course, were recruited via an email sent to all students enrolled in the course (2403 students; response rate = 72.9%) and received course credit for participation. The introductory geography course was selected as it was a general education course open to all students and attracted a diverse group of students (e.g., various majors, year of study, ethnicity, age, and gender).

Psychometrics Soundness

The survey consisted of 21 items across four areas, basic knowledge of engineering and engineers (3 items), impacts of engineering on human life (4 items), thinking and acting like an engineer (7 items), and basic skills in the use of technologies (7 items). In a previous pilot of the engineering literacy survey, the yielded a Cronbach's alpha of .93, with subscale alphas of .90, .82, .89, and .91, respectively. The previous pilot also confirmed the presence of the four factors/areas.

To confirm the psychometric soundness of the survey, the present data were subjected to a factor analysis as well. The central question to be addressed is whether the 4 areas of the survey constitute reliable factors. A first analysis determined that internal consistency (Cronbach's alpha) across the 21 items was sufficient, $\alpha = .94$. All criteria validating the use of factor analysis were satisfied: adequate sample size, Kaiser-Meyer-Olkin (KMO) sampling adequacy of .95, and Bartlett's test of sphericity was significant, χ^2 (210) = 23712.20, $p < .01$; thus, a factor analysis was conducted using the Maximum Likelihood extraction method with the Promax with Kaiser Normalization rotation method ($\kappa = 4$) on the 21 items to determine if they comprise the four areas of engineering literacy identified through the previous pilot test. The number of factors retained was initially determined through a scree test and eigenvalues greater than 1, resulting in 3 factors explaining 67.6% of the variance. To verify this conclusion, three factor analyses were conducted setting the number of factors to extract to 2, 3, and 4; however, only one factor analysis (4 factors) met all of the necessary criteria of loadings above .40, no crossloaded items, no factors with fewer than three items, and interpretable factor item clusters (see Table 1).[7, 8] The four factor model aligned with the four factors from the pilot study and explained 71.9% of the variance (see Table 2). These results provide support for the use of the engineering literacy survey as a reliable instrument as evaluate students.

Table 2. Component Loadings (Pattern Matrix) for 21 Items[*]

	Components			
	1 **Knowledge**	**2** **Impact**	**3** **Think/Act**	**4** **Skills**
1. I understand basic engineering terms	-.895	-	-	
2. I understand what an engineer does	-.905			
3. I understand basics of design process	-.720	-.282		-
4. I see the impact of engineering	-	-.698	-	
5. I see engineering's impact on society	-.101	-.830	-	
6. I see society's impact on engineering	-.123	-.829		-
7. I understand engineering risks	-.114	-.730		
8. I consider benefits/risk or action			-.812	-
9. I learn new technologies			-.485	-.346
10. I believe non-engineers contribute	-	-.246	-.463	-.183
11. I identify problems to be solved	-.270	-.110	-.718	
12. I think about multiple perspectives	-.140	-.146	-.947	
13. I take into account cultural views	-.101	-.118	-.801	
14. I believe in acting ethically	-.294	-.232	-.537	-.206
15. I use basic technologies effectively	-.207	-		-.823
16. I use web technologies effectively	-.109			-.894
17. I use word processors effectively	-.220	-.177		-.843
18. I use presentation apps effectively	-.161		-	-.874
19. I use math skills effectively	-.203	-		-.832
20. I learn new technologies effectively		-.137		-.923
21. I like to learn new technologies	-.104			-.662
Eigenvalues	1.03	0.89	2.30	10.87
% of Total Variance	4.91	4.24	10.96	51.77
Cronbach's Alpha	.89	.86	.89	.93
Number of items	3	4	7	7

[*]Loadings => .10

Results

Student Perceptions of Engineering Literacy

Did students differ in their engineering literacy sub-scale scores – knowledge, impact, thinking/acting, and skills? A within-subjects ANOVA was implemented to examine the data yielding a statistically significant main effect for the engineering literacy subscales, $F(3,4485) = 722.76$, $\eta_p^2 = .32$, $p < .01$. Given the statistically significant main effect, subsequent Bonferroni post-hoc analyses indicated that students scored statistically highest on the skills subscale (M = 5.31, SD = .78) and statistically lowest on the knowledge subscale (M = 4.32, SD = 1.29), with the impact (M = 5.12, SD = .83) and thinking/acting (M = 5.12, SD = .76) subscales in the middle and not statically different from each other. These results indicate that students perceived their use of basic technology skills more highly, while perceiving their basic engineering knowledge much more problematically.

Non-Engineers Only. Given the interest in the engineering literacy of non-engineers, each of the analyses within this study will be conducted with and without the engineering students included. This will provide an indication of perceptions within the general university sample, as well as within only the non-engineers. Thus, did non-engineering students differ in their engineering literacy sub-scale scores? A within-subjects ANOVA was implemented to examine the data yielding a statistically significant main effect for the engineering literacy subscales, $F(3,2607) = 831.75$, $\eta_p^2 = .48$, $p < .01$. Given the statistically significant main effect, subsequent Bonferroni post-hoc analyses indicated that students scored statistically higher on each sub-scale in the following order, highest to lowest: skills (M = 5.23, SD = .77), thinking/acting (M = 5.01, SD = .82), impact (M = 4.95, SD = .82), and knowledge (M = 3.76, SD = 1.21).

<u>Engineering Literacy and Gender</u>

Do male and female students perceive their engineering literacy differently? A composite engineering literacy score was created for student by averaging their four sub-scales. An ANOVA was conducted examining the composite engineering literacy score across gender resulting in a statistically significant difference, $F(1, 1471) = 63.53$, $\eta_p^2 = .04$, $p < .01$. Given the statistically significant results, a series of four pairwise comparisons (male, female) was computed for each of the four subscales (knowledge, impact, thinking/acting, skills). The results indicate that males reported significantly higher engineering literacy knowledge, t(1471) = 11.60, d = .61, p < .01; engineering literacy impact, t(1471) = 6.66, d = .35, p < .01; engineering literacy thinking/acting, t(1471) = 2.94, d = .15, p < .01; and, engineering literacy skills, t(1471) = 2.38, d = .12, p < .01 (see Table 3). That said, the effect sizes of the four comparisons would be considered medium (knowledge, impact) to low (thinking/acting, skills).

Table 3. Means and Standard Deviations for Gender for the Knowledge, Impact, Thinking/Acting, and Skills Engineering Subscales Including Engineers

	Engineering Literacy Subscales Including Engineers							
	Knowledge		Impact		Thinking/Acting		Skills	
	M	SD	M	SD	M	SD	M	SD
Male	4.61	1.17	5.24	.80	5.17	.76	5.35	.79
Female	3.84	1.34	4.95	.83	5.05	.76	5.25	.77

Non-Engineers Only. Do male and female non-engineering students perceive their engineering literacy differently? An ANOVA was conducted examining the composite engineering literacy score across gender for non-engineering students resulting in a statistically significant difference, $F(1, 859) = 4.67$, $\eta_p^2 = .02$, $p < .01$. Given the statistically significant results, a series of four pairwise comparisons (male, female) was computed for each of the four subscales. The results indicate that males reported significantly higher engineering literacy knowledge, t(989) = 53.85, d = .46, p < .01; and engineering literacy impact, t(974) = 14.77, d = .21, p < .01. There were no significant differences in engineering literacy thinking/acting, t(945) = 1.95, d = .09, p = .16; and, engineering literacy skills, t(946) = .82, d = .06, p = .36 (see Table 4). In addition, the effect sizes of the two statistically significant comparisons would be considered medium (knowledge) and low (impact).

Table 4. Means and Standard Deviations for Gender for the Knowledge, Impact, Thinking/Acting, and Skills Engineering Subscales Excluding Engineers

	Engineering Literacy Subscales Including Engineers							
	Knowledge		Impact		Thinking/Acting		Skills	
	M	SD	M	SD	M	SD	M	SD
Male	4.03	1.13	5.03	.79	5.03	.74	5.25	.76
Female	3.48	1.21	4.82	.85	4.96	.77	5.20	.79

<u>Engineering Literacy and Ethnicity</u>

Did students of different ethnic backgrounds – Caucasian/white, Africa American/black, Asian, Hispanic, Alaskan Native/American Indian, Multiracial – differ in their engineering literacy? An ANOVA was conducted examining the composite engineering literacy score across ethnicity resulting in no statistically significant main effect, F(4, 1478) = 1.90, η_p^2 = .005, *p* = .10. Beyond examining the overall composite score, students' sub-scales – knowledge, impact, thinking/acting, and skills – were also examined by ethnicity using a one-way ANOVA. Only two of the four ANOVAs yielded significant results, impact and thinking/acting: knowledge, F(4,1669) = 2.07, η_p^2 = .005, *p* = .08; impact, F(4,1645) = 2.62, η_p^2 = .006, *p* = .03; thinking/acting, F(4,1609) = 4.23, η_p^2 = .01, *p* < .01; and skills, F(4,1598) = 2.13, η_p^2 = .005, *p* = .07 (see Table 5). Tukey post-hoc analysis indicated that Hispanic students scored higher on impact than African American/black students, t(847) = 3.00, d = .23, p < .01; and Hispanic students scored higher on thinking/acting than both African American/black students, t(823) = 3.97, d = .32, p < .01, and Caucasian/white students t(711) = 3.40, d = .28, p < .01.

Table 5. Means and Standard Deviations for Ethnicity for the Knowledge, Impact, Thinking/Acting, and Skills Engineering Subscales Including Engineers

	Engineering Literacy Subscales Including Engineers							
	Knowledge		Impact		Thinking/Acting		Skills	
	M	SD	M	SD	M	SD	M	SD
Caucasian/White	4.36	1.14	5.10	.82	5.07	.77	5.26	.79
African American/Black	4.20	1.26	5.01	.84	5.04	.78	5.28	.81
Asian	4.21	1.40	5.14	.85	5.14	.74	5.32	.75
Hispanic	4.41	1.40	5.20	.78	5.27	.65	5.42	.66
Alaskan Native/ American Indian	4.43	1.32	5.05	.43	4.94	.57	5.08	.74

Non-Engineers Only. Did non-engineering students of difference ethnic backgrounds differ in their engineering literacy? An ANOVA was conducted examining the composite engineering literacy score across ethnicity of non-engineers resulting in no statistically significant main effect, F(4, 862) = 1.60, η_p^2 = .007, *p* = .17 (see Table 5). Beyond examining the overall composite score, non-engineering students' sub-scales were also examined by ethnicity using one-way ANOVAs. Only one of the four ANOVAs yielded significant results, knowledge: knowledge, F(4,991) = 3.01, η_p^2 = .012, *p* = .01; impact, F(4,978) = 1.50, η_p^2 = .006, *p* = .19; thinking/acting, F(4,948) = 2.35, η_p^2 = .01, *p* = .052; and skills, F(4,949) = .58, η_p^2 = .002, *p* = .67 (see Table 6). Tukey post-hoc analysis indicated that Caucasian/White, Alaskan Natives/American Indians, and Hispanic students scored higher on knowledge than African American/Black and Asian students (p < .05).

Table 6. Means and Standard Deviations for Ethnicity for the Knowledge, Impact, Thinking/Acting, and Skills Engineering Subscales Excluding Engineers

	Engineering Literacy Subscales Excluding Engineers							
	Knowledge		Impact		Thinking/Acting		Skills	
	M	SD	M	SD	M	SD	M	SD
Caucasian/White	3.95	1.19	4.99	.77	5.14	.77	5.24	.75
African American/Black	3.74	1.15	4.84	.84	4.92	.79	5.20	.82
Asian	3.54	1.26	4.93	.87	4.96	.75	5.19	.76
Hispanic	3.75	1.27	4.97	.80	5.14	.68	5.30	.70
Alaskan Native/ American Indian	3.83	1.37	4.93	.12	5.00	.54	5.07	.58

<u>Engineering Literacy and Curricular Focus</u>

Did students enrolled in different majors within specific colleges differ in their engineering literacy? A one-way ANOVA was conducted examining the engineering literacy composite score across colleges (the School of Medicine and Graduate School students were excluded as there were only 2 students from each college), F(6, 1460) = 43.31, η_p^2 = .15, *p* < .01 (see Table 6). Given the statistically significant results, subsequent Tukey post-hoc analyses revealed that the College of Engineering students has the highest reported engineering literacy among the colleges. Beyond having significantly higher engineering literacy composite scores, students from College of Architecture and Urban Students and the College of Science scored significantly higher than students from the Colleges of Business, Agriculture and Life Sciences, and Liberal Arts and Human Sciences.

In addition, students' sub-scales – knowledge, impact, thinking/acting, and skills – were also examined by college using one-way ANOVAs. Each of the four ANOVAs yielded significant results: knowledge, F(6,1648) = 112.77, η_p^2 = .29, *p* < .01; impact, F(6,1623) = 22.26, η_p^2 = .07, *p* < .01; thinking/acting, F(6,1586) = 10.34, η_p^2 = .03, *p* < .01; and skills, F(6,1580) = 4.99, η_p^2 = .01, *p* < .01. The Tukey post-analyses are reported in Tables 7-10.

Non-Engineers Only. Did non-engineering students enrolled in difference majors within specific colleges differ in their engineering literacy. A one-way ANOVA was conducted examining the engineering literacy composite score of non-engineers across colleges, F(5, 865) = 3.98, η_p^2 = .02, *p* < .01 (see Table 7). Given the statistically significant results, subsequent Tukey post-hoc analyses revealed that the College of Liberal Arts and Human Science students had the lowest reported engineering literacy among the non-engineering colleges (p < .05).

In addition, non-engineering students' sub-scales were also examined by college using one-way ANOVAs. Two of the four ANOVAs yielded significant results, knowledge and impact: knowledge, $F(5,995) = 7.40$, $\eta_p^2 = .03$, $p < .01$; impact, $F(6,981) = 2.50$, $\eta_p^2 = .01$, $p = .02$; thinking/acting, $F(6,951) = 1.34$, $\eta_p^2 = .01$, $p = .24$; and skills, $F(6,952) = 1.05$, $\eta_p^2 = .01$, $p = .38$. The Tukey post-analyses are reported in Tables 8-11.

Table 7. Comparison of Engineering Literacy Composite Scores *across Colleges both Including and Excluding Engineers*

		Including Engineers		Excluding Engineers	
	n	M	SD	M	SD
Engineering	589	5.32[a]	.71		
Architecture and Urban Studies	75	4.95[b]	.49	4.95[a]	.49
Science	221	4.84[b]	.76	4.84[a]	.76
Natural Resources and the Environment	33	4.72[b,c]	.57	4.72[a]	.57
Business	301	4.71[c]	.70	4.71[a]	.70
Agriculture and Life Sciences	91	4.69[c]	.68	4.69[a]	.68
Liberal Arts and Human Sciences	150	4.58[c]	.69	4.58[b]	.69
Total:	1460				

Note: Means with similar superscripts are statistically similar, means with dissimilar superscripts are statistically different.

Table 8. Comparison of the Knowledge *Engineering Literacy Sub-score across Colleges both Incuding and Excluding Engineers*

		Including Engineers		Excluding Engineers	
	n	M	SD	M	SD
Engineering	647	5.12[a]	0.88		
Science	242	3.99[b]	0.97	3.99[a]	0.97
Architecture and Urban Studies	87	3.97[b]	1.25	3.97[a,b]	1.25
Business	351	3.77[b,c]	1.05	3.77[a,b]	1.05
Natural Resources and the Environment	37	3.73[c]	1.17	3.73[a,b]	1.17
Agriculture and Life Sciences	100	3.72[c]	1.19	3.72[b]	1.19
Liberal Arts and Human Sciences	184	3.32[d]	1.25	3.32[b]	1.25
Total:	1648				

Note: Means with similar superscripts are statistically similar, means with dissimilar superscripts are statistically different.

Table 9. Comparison of the Impact *Engineering Literacy Sub-score across Colleges*

		Including Engineering		Excluding Engineering	
	n	M	SD	M	SD
Engineering	636	5.36[a]	.75		
Architecture and Urban Studies	83	5.09[b]	.65	5.09[a]	.65
Natural Resources and the Environment	38	5.03[b]	.66	5.03[a]	.66
Science	239	5.01[c]	.88	5.01[a,b]	.88
Agriculture and Life Sciences	102	4.90[c]	.77	4.90[a,b]	.77
Business	340	4.86[c]	.86	4.86[b]	.86
Liberal Arts and Human Sciences	185	4.80[d]	.80	4.80[b]	.80
Total:	1623				

Note: Means with similar superscripts are statistically similar, means with dissimilar superscripts are statistically different.

Table 10. Comparison of the Thinking/Acting *Engineering Literacy Sub-score across Colleges*

		Including Engineering		Excluding Engineering	
	n	M	SD	M	SD
Engineering	629	5.27[a]	.72		
Architecture and Urban Studies	82	5.16[b]	.57	5.16[a]	.57
Science	235	5.04[b]	.80	5.04[a]	.80
Natural Resources and the Environment	36	4.96[b]	.59	4.96[a]	.59
Business	327	4.95[b]	.81	4.95[a]	.81
Liberal Arts and Human Sciences	178	4.95[b]	.75	4.95[a]	.75
Agriculture and Life Sciences	99	4.95[b]	.72	4.95[a]	.72
Total:	1586				

Note: Means with similar superscripts are statistically similar, means with dissimilar superscripts are statistically different.

Table 11. Comparison of the Skills *Engineering Literacy Sub-score across Colleges*

		Including Engineering		Excluding Engineering	
	n	M	SD	M	SD
Engineering	622	5.42[a]	.71		
Architecture and Urban Studies	83	5.37[a]	.49	5.37[a]	.49
Science	230	5.27[b]	.76	5.27[a]	.76
Business	333	5.19[b]	.57	5.19[a]	.57
Natural Resources and the Environment	38	5.19[b]	.70	5.19[a]	.70
Agriculture and Life Sciences	104	5.18[b]	.68	5.18[a]	.68
Liberal Arts and Human Sciences	170	5.18[c]	.69	5.18[a]	.69
Total:	1580				

Note: Means with similar superscripts are statistically similar, means with dissimilar superscripts are statistically different.

Engineering Literacy and Grade Level

Did students at difference grade levels – freshman, sophomores, junior, and seniors – differ in their engineering literacy? An ANOVA was conducted examining the composite engineering literacy score across grade levels resulting in no statistically significant main effect, $F(3, 1422) = .77$, $\eta_p^2 = .002$, $p = .51$. Beyond examining the overall composite score, students' sub-scales – knowledge, impact, thinking/acting, and skills – were also examined by grade level using a one-way ANOVA. Only one of the four ANOVAs yielded significant results, skills: knowledge, $F(3,1606) = 1.64$, $\eta_p^2 = .003$, $p = .17$; impact, $F(3,1579) = 1.11$, $\eta_p^2 = .002$, $p = .34$; thinking/acting, $F(3,1545) = 1.14$, $\eta_p^2 = .002$, $p = .33$; and skills, $F(3,1536) = 6.09$, $\eta_p^2 = .01$, $p < .01$ (see Table 12). Tukey post-hoc analysis indicated that Freshman scored significantly higher than Juniors on technology skills, $t(1429) = 4.122$, $d = 0.24$, $p < .01$, however, the effect size was small.

Table 12. Means and Standard Deviations for Grade Level for the Knowledge, Impact, Thinking/Acting, and Skills Engineering Subscales Including Engineers

	Engineering Literacy Subscales, Including Engineers							
	Knowledge		Impact		Thinking/Acting		Skills	
	M	SD	M	SD	M	SD	M	SD
Freshman	4.26	1.30	5.11	.80	5.12	.73	5.34	.75
Sophomores	4.37	1.18	5.12	.76	5.10	.72	5.34	.67

Juniors	4.41	1.20	5.03	.91	5.04	.83	5.14	.86
Seniors	4.44	1.07	5.19	.68	5.11	.60	5.41	.70

Non-Engineers Only. Did non-engineering students at different grade levels differ in their engineering literacy? An ANOVA was conducted examining the composite engineering literacy score across grade levels for non-engineers only resulted in no statistically significant main effect, $F(3, 821) = .05$, $\eta_p^2 < .001$, $p = .95$. Beyond examining the overall composite score, non-engineering students' sub-scales – knowledge, impact, thinking/acting, and skills – were also examined by grade level using a one-way ANOVA. None of the four ANOVAs yielded significant results: knowledge, $F(3,943) = 2.19$, $\eta_p^2 = .005$, $p = .20$; impact, $F(3,929) = .80$, $\eta_p^2 < .001$, $p = .97$; thinking/acting, $F(3,899) = .24$, $\eta_p^2 = .001$, $p = .86$; and skills, $F(3,903) = .63$, $\eta_p^2 = .002$, $p = .59$ (see Table 13).

Table 13. Means and Standard Deviations for Grade Level for the Knowledge, Impact, Thinking/Acting, and Skills Engineering Subscales Excluding Engineers

	Engineering Literacy Subscales, Excluding Engineers							
	Knowledge		Impact		Thinking/Acting		Skills	
	M	SD	M	SD	M	SD	M	SD
Freshman	3.72	1.19	4.92	.79	5.00	.73	5.40	.76
Sophomores	3.82	1.22	4.87	.87	4.91	.77	5.23	.76
Juniors	3.94	1.25	4.94	.95	4.96	.85	5.23	.88
Seniors	3.85	0.93	4.93	.66	4.97	.63	5.17	.56

Conclusions

This survey resulted in four broad conclusions regarding the data that included the engineering students. First, there were little to no meaningful differences in the subscales when comparing students of various ethnicities. Second, there were also no meaningful differences in the subscales when comparing student of difference grade levels. It is interesting in that, despite additional time in formal education, seniors did not score meaningfully higher than freshman students. Third, though male students scored higher than females on all four engineering literacy subscales, the effects sizes were medium to small. And fourth, students with an engineering background (i.e., students whose majors are in the College of Engineering) had meaningfully higher engineering literacy than students with any other academic background (i.e., students whose majors were in a college other than Engineering). Additional analysis of the survey results revealed that, while scoring higher than other colleges, the College of Engineering had statistical similarities with a variety of other colleges.

In addition, there were a series of analyses that addressed only non-engineering students. These results should be understood to be a sub-set of the overall analyses (i.e., engineers and non-engineers), thus there are few differences. Overall, when examining the four subscales, non-engineers perceived their engineering literacy skills more highly than their knowledge skills. In terms of gender, non-engineering males perceived their engineering literacy knowledge and impact higher than non-engineering females, although not thinking/acting or skills, and the differences in knowledge and impact were relatively small. With regard to differences based on non-engineering students' ethnicity, there was no overall perceived engineering literacy differences, and only one subscale demonstrated a significant difference, Caucasian/White, Alaskan Natives/American Indians, and Hispanic students scored higher on knowledge than

African American/Black and Asian students. An examination of non-engineering students based on their college reveals students from the College of Liberal Arts and Human Sciences have the lowest perceptions of their engineering literacy. Further, when student perceptions were examined by college based on the subscales, there are only minor differences with a small advantage for students in the College of Architecture and Urban Studies and the College of Science. Finally, when non-engineering students' perceptions of their engineering literacy was examined by grade level (first year to forth year), there were no differences.

Overall, engineering students demonstrate higher engineering literacy than non-engineering students, and within non-engineering students there are some relatively small and non-systematic differences in perception.

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Survey (appendix A)

	Strongly Disagree 1	Disagree 2	Somewhat Disagree 3	Somewhat Agree 4	Agree 5	Strongly Agree 6
Basic Knowledge of Engineering and Engineers						
1. I can carry on a conversation with an engineer that involves basic engineering terms, ideas, or principles.						
2. I have a basic understanding of what engineers do on a daily basis.						
3. I understand the basics of the engineering design process, including its limitations.						
Impacts of Engineering on Human Life						
1. I can see the impact of engineering on everyday life all around me.						
2. I am aware of how engineering has helped to shape human history.						
3. I am aware of how engineering is affected by human culture and society.						
4. I understand that all engineering projects entail risk.						
Thinking and Acting Like an Engineer						
1. I consider the benefits and risks of an action before engaging.						
2. I am willing to engage with and learn about new technologies.						
3. I believe engineers and non-engineers can contribute meaningfully to engineering projects.						
4. I enjoy identifying problems to be solved and implementing practical solutions.						
5. I think about problems and solutions from multiple perspectives before acting.						
6. I recognize that problems solutions need to be sensitive to the cultural situation.						
7. I believe in acting in an ethical manner.						
Basic Skills in the Use of Technologies						
1. I have the basic skills of using a variety of technologies effectively.						
2. I can use the Internet and web-based applications effectively.						
3. I have the basic skills to use a word processor effectively.						
4. I have the basic skills to use presentation software effectively (e.g., PowerPoint, Prezi).						
5. I have the basic skills to use mathematics effectively.						
6. I have the basic skills to learn new technologies effectively.						
7. I am interested in learning how to more efficiently use technologies.						