

What brings women to the table? Female and male students' perceptions of ways of thinking in engineering study and practice

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Abstract - Women represent only one fifth of engineering Bachelor's degree recipients in the U.S. This gender gap has stubbornly held for the past several years. Based on survey and interview data, this study examines the experiences and perspectives of 40 first-year women and men intending to study engineering at a public, research extensive university. We found that, regardless of gender, students view math, science, and other technical abilities as foundational in engineering. However, our findings also provide a complex picture of gender differences in the experiences and ways of thinking beginning undergraduates associate with engineering. With a more detailed understanding of what distinguishes women as early successes in the possible engineering pathways, this study provides empirical grounds for portraying engineering more broadly in order to recruit more women.

Index Terms - gender, engineering education, mixed methods, recruitment

INTRODUCTION AND LITERATURE REVIEW

Narrowing the gender gap in engineering has remained an elusive goal for many years. From 1995 to 2004, only 20% of Bachelor's degrees in engineering were granted to women, with little change during the five-year period [1]. A growing body of research suggests that engineering programs have trouble both recruiting and retaining women, in spite of their being academically qualified to succeed as engineering majors [2][3]. Research suggests a variety of reasons why women leave engineering, ranging from dissatisfaction with academic programs to climate issues such as competitiveness and negative interactions with faculty and peers [2]–[4]. However, there does not appear to be a substantial difference in satisfaction, motivation, and behavior between persisters and leavers [4]. Isaacs' analysis of enrollment data from the American Association of Engineering Societies found that women do not drop out of engineering at a greater rate than men [5]. NSF data also show that women's enrollment rates are similar to their graduation rates [6][7].

According to research on recruitment, factors related to women's choice to study engineering include early interest and ability in math and science, applications of engineering,

and self-confidence [2][4]. Huang *et al.*'s national study suggested that women who study science and engineering comprise a highly selective population [8]. To complement findings on reasons why women leave engineering and to better understand the reasons why women select engineering, our study focuses on what distinguishes students, particularly women, as early successes in the engineering pipeline.

This paper examines the experiences and perspectives of 40 first-year women and men intending to study engineering at "West State," a public, research extensive university in the western U.S. In addition to our findings, we offer this work as a demonstration of the unique strengths of mixed-methods research. Our analyses integrate quantitative and qualitative data collected as part of the Academic Pathways Study (APS), a multi-institutional, longitudinal study of engineering student learning and development [9].

We found similarities and differences between first-year women and men that may offer insight into women's perceptions of engineering upon entry into higher education. For example, regardless of gender, participants considered technical knowledge and skills (*e.g.*, math, science, computing) to be more important than professional and interpersonal skills (*e.g.*, communication, business). However, when asked to describe qualitatively how they perceived engineering and the skills required of engineers, differences emerged in how women and men answered. Our findings suggest that rather than differences in abilities or interest, differences in men's and women's perceptions of what is required for engineering may be one explanation for the gender gap in engineering.

METHODOLOGY

The data gathered, analyzed, and reported in this study were collected as part of the APS, a longitudinal, mixed-methods study of 160 engineering students at four distinct institutions with engineering programs. West State participants were recruited by advertising the study in first-year courses identified as prerequisites for the engineering programs, as well as engineering student associations and interest groups for pre-engineering students. Women were oversampled: While 17% of engineering students at West State are women, there are 17 female participants in this study (43%).

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The APS employed four primary investigative tools: in-depth interviews (both structured and unstructured), surveys, ethnographic observations, and performance tasks, in which participants were asked to complete a small engineering problem. Each tool complements the others, with the goal of achieving a rich, holistic understanding of engineering student learning and development in the college years [10]. A mixed-methods research design enables researchers to both confirm existing theories while also breaking new theoretical ground, an opportunity typically not available to strictly quantitative or qualitative designs alone [11]. Furthermore, a design such as the APS's allows both breadth and depth of insight, providing not only the power of triangulation to improve accuracy, but also an enhanced ability to represent diverse perspectives on complex phenomena such as learning and development.

To explore the intersection of gender and first-year students' expectations of what it means to study and practice engineering, we considered three sources of data from the APS. The first dataset was elicited by a survey question asking students to rate a set of skills and abilities in terms of their importance for becoming a successful engineer. The second dataset was elicited by an open-ended survey question asking students to list five terms they would use to describe engineering. The third dataset was elicited by structured interview questions asking students to reflect in their own words on engineering as a field of study and as a profession.

SKILLS AND ABILITIES IMPORTANT IN ENGINEERING

As part of the survey [12] given in both the winter and spring of the first year, students were asked, "How important do you think each of the following skills and abilities is to becoming a successful engineer?" The skills listed were public speaking ability, math ability, science ability, computer and programming skills, written communications, and business ability. The scale for rating these abilities was 0 to 4 for "not important," "somewhat important," "important," "very important," and "crucial," respectively.

We discuss results from the winter survey here, because there was little difference between the results of the winter and spring surveys, and because we wanted to capture students' perceptions of engineering early in their educational program.

As shown in Table I, West State students rated technical knowledge and skills like math, science, and computing as "very important" to "crucial" for a successful engineer, in contrast with lower ratings for professional and interpersonal knowledge and skills like public speaking ability, written communication and business ability.

TABLE I
IMPORTANCE OF SKILLS IN ENGINEERING, WEST STATE (n = 40)

Skill	Mean	Median	Std Dev.
Public speaking ability	1.95	2.00	1.08
Math ability	3.58	4.00	0.78
Science ability	3.38	4.00	0.78
Computer/programming skills	2.70	3.00	0.88
Written communication	2.63	3.00	0.95
Business ability	1.85	2.00	1.10

TABLE II
CORRELATION MATRIX, IMPORTANCE OF SKILLS IN ENGINEERING, WEST STATE (n = 40)

	Math	Science	Computer	Public speaking	Written comm.
Science	0.79*				
Computer	0.45*	0.46*			
Public speaking	0.06	0.05	0.07		
Written comm.	0.05	0.24	0.18	0.53*	
Business	0.21	0.13	0.13	0.52*	0.54*

*Correlation is significant at the $p < 0.01$ level (two-tailed).

Using Spearman rank correlations, students' ratings of the importance of math and science ability and computer and programming skills were all highly correlated, and ratings of the importance of public speaking, written communication, and business ability were all highly correlated. Students perceived the former category of technical knowledge and skills to be more important to becoming a successful engineer than the latter category of professional and interpersonal knowledge and skills. (We intend to refine this analysis by examining survey variables [12], rather than individual items.)

Table III shows how first-year women and men rated each of the skills in the winter survey. We found no statistically significant difference between women's and men's ratings of the importance of each of these skills (Mann-Whitney, significance level of 0.05).

TABLE III
RATINGS OF IMPORTANT ABILITIES, BY GENDER, WEST STATE (n = 40)

	Skill	Mean	Median	Std Dev.
Female	Public speaking ability	1.76	1.00	1.30
	Math ability	3.35	4.00	0.93
	Science ability	3.25	3.50	0.93
	Computer/programming skills	2.82	3.00	0.81
	Written communication	2.88	3.00	1.05
	Business ability	1.71	1.00	1.16
Male	Public speaking ability	2.09	2.00	0.90
	Math ability	3.74	4.00	0.62
	Science ability	3.48	4.00	0.67
	Computer/programming skills	2.61	3.00	0.94
	Written communication	2.43	2.00	0.84
	Business ability	1.96	2.00	1.07

Based on these findings, we observe that in this sample, both female and male first-year students view technical knowledge and skills as foundational to becoming a successful engineer. In the next section, we introduce qualitative data that support this finding but also begin to reveal the complexity with which students view engineering study and practice.

PERCEPTIONS OF ENGINEERING'S VALUE AND WAYS OF THINKING IN ENGINEERING

On the Year 1 winter survey, students were asked, "In the space provided, list five terms you would use to describe 'engineering.'" The data gathered consisted of a list of words and phrases in response to this open-ended question.

I. Data Collection and Analysis

Out of 160 student participants across all APS institutions, 153 (60 women, 93 men) provided at least one term in response to the question. In total, the dataset consisted of 751 terms (while most students provided five terms, some provided fewer). In the first phase of the analysis, the data were examined exhaustively, resulting in groups of closely lexically related or synonymous terms and counts of each term or group. The most frequently cited groups of terms and their counts are shown in Table IV. Terms or groups of terms mentioned ten times or more comprised 628 responses or 83.6% of all responses in the dataset and therefore represent a substantial majority of terms offered by students.

These terms and groups of terms were then analyzed using a constant comparative approach, by which they were compared and contrasted with one another to identify higher-level, organizing categories [13]. Two broad themes emerged: “the value of engineering” and “engineering ways of thinking.” By the former, we mean terms students use to evaluate the effects of engineering on themselves, their environments, and society in general. By engineering ways of thinking, we mean ways of knowing, thinking, and learning that engineers engage in.

Table IV contains the distribution of these terms into the two broad themes. The labels for the groups of closely related terms organized within each broad theme have been simplified. For example, the group “challenging/difficult” contains not only “challenging” and “difficult” but also “hard,” “time-consuming,” “laborious,” and “demanding.”

The value of engineering for individuals includes both intrinsic and extrinsic factors. For example, descriptions of engineering as interesting or fun were interpreted as references to intrinsic motivation to do engineering. Descriptions of engineering as difficult or boring were interpreted as references to intrinsic demotivation to do engineering. Terms

related to the financial and status-oriented rewards of engineering were interpreted as references to extrinsic motivation to do engineering. The value of engineering to a particular environment or society at large is indicated by more abstract terms like “essential” or “useful.”

Three categories representing “engineering ways of thinking” emerged from the data: (1) math-science-logical thinking, (2) creative-innovative thinking, (3) active-experiential thinking. Math-science-logical thinking is defined here as a thought process that is primarily logical, sequential, rational, and focused on the parts of the whole. Creative-innovative thinking is defined here as primarily intuitive, creative, synthesizing, and focused on the whole. Active-experiential thinking is defined here as a thought process that occurs in conjunction with action and experience, resulting in reflective knowledge that can only come from interaction with the objects of one’s thoughts.

II. Findings

Some students offered more than one term that was organized into a particular category. For example, several students used both “math” and “science,” both of which are interpreted as belonging to the “math-science-logical thinking” category of engineering ways of thinking. To gain a better understanding of the frequency with which first-year students describe engineering with respect to the broad themes offered in this paper, it is appropriate to analyze the data in terms of *student* counts rather than *term* counts, to eliminate “double counting” in any of the categories.

Because we are limited by the format of the question, which did not direct students to comment specifically on the value of engineering or ways of engineering thinking, we cannot conclude that these are the only values or ways of thinking that these students associate with engineering. However, because such a large percentage of students used terms that suggest one of these values of engineering and/or ways of engineering thinking without being prompted, we can interpret these emergent themes to be of importance to students when they think about the study and practice of engineering. All 153 students contributed at least one term that was coded into one of the two broad themes. 73% of the students contributed at least one term that was coded as a value of engineering. 86% contributed at least one term that was coded as an engineering way of thinking.

63% of the 153 students offered at least one term describing the intrinsic values associated with engineering. Only 27% of students described engineering’s value to society, and 16% offered at least one term describing the extrinsic values associated with engineering. Generally, differences between the ways women and men described engineering in terms of the value of engineering were not significant. Of particular interest are small but suggestive differences in how women and men perceived engineering to be intrinsically valuable. Women were more likely than men to offer at least one term describing the intrinsic values associated with engineering. However, women were slightly

TABLE IV
DISTRIBUTION OF MOST FREQUENTLY CITED GROUPS OF TERMS INTO BROAD ANALYTICAL THEMES AND CATEGORIES

Value of engineering	count	Ways of engineering thinking	count
<u>Individual intrinsic</u>		<u>Math-science-logical</u>	
challenging/difficult	81	logical	34
interesting	47	math	31
fun	22	science	29
exciting	11	tech & computers	15
<u>Individual extrinsic</u>		analytical	10
financially rewarding	11	technical	17
<u>Value to society</u>		<u>Creative-innovative</u>	
essential/important	19	creative	58
useful	25	innovative	54
		current / cutting edge	12
		<u>Active-experiential</u>	
		practical	39
		problem solving	36
		design	22
		building & construction	10
		<u>Others</u>	
		intelligent	17
		teamwork	15
		interdisciplinary	14

less inclined to describe engineering as intrinsically motivating (e.g., fun, exciting, rewarding), while slightly more inclined to describe the demotivational qualities of engineering (difficult, stressful, boring). We must emphasize that these differences were not statistically significant but suggest a route for further inquiry.

As described above, when asked for five terms describing engineering, a large majority of students included at least one term referring to a way of thinking. Our evidence is not conclusive but suggests that some students perceive engineering thinking more broadly than others. Across institutions, women were less likely than men to provide both a math-science-logical thinking term and a creative-innovative term to describe engineering. This trend is more pronounced at West State. Nearly half of the men at West State listed both a term like “math” and a term like “creative,” while approximately one quarter of the women did.

These findings suggest that when given the opportunity to reflect qualitatively about their understanding of engineering, both women and men thought beyond math and science toward other ways of thinking. At West State, women were less likely than men to mention active-experiential thinking and somewhat more likely to mention creativity-innovation. More interestingly, women thought more narrowly about engineering thinking than did men, who were more likely to offer multiple ways of thinking.

These findings, in combination with those in the previous section, may indicate that while all first-year students acknowledge the importance of math and science to the study and practice of engineering, women are less likely than men to view engineering as a complex study involving not only math-science-logical but also creative-innovative and active-experiential ways of thinking. It is no surprise, then, that women are somewhat less likely than men to perceive engineering as intrinsically rewarding, but somewhat more likely than men to perceive engineering as intrinsically unrewarding. At this time, we do not know if the relationship between how women perceive engineering ways of thinking is related to their evaluation of engineering in general, but the data suggest yet another intriguing direction for future study. In the next section, we show an even more detailed picture of engineering ways of thinking elicited in structured interviews.

PERCEPTIONS OF ENGINEERING THINKING OF VARYING DEGREES OF COMPLEXITY

Structured, qualitative interviews were given to 29 students at West State during their first year. A set of 28 questions, mostly open-ended, was developed for these interviews. Questions were designed to elicit information about students’ perceptions of and reflections on engineering, engineers, and relevant educational experiences thus far.

I. Data collection and analysis

Analysis of the data was conducted using ATLAS.ti, computer-assisted, qualitative data analysis software that provides researchers with assistance managing data, coding,

and theory-building. One researcher went through the transcripts, assigning preliminary codes to students’ comments. Codes that had high numbers of quotations assigned to them suggested emergent themes, which were then further explored. At least one and often two additional members of the research team reviewed each of these collections of quotations and provided feedback on the meanings of the codes and the extent to which each could be further articulated and/or categorized.

Codes were combined by similarity to complement the findings that emerged from the quantitative and “five terms” data, as described earlier. For example, the math-science-logical family contained all quotations that had been assigned one or more of the following codes: analytical, detail oriented, logical, math, objective, science, and technically minded. Representative quotations from these families were selected to enrich our understanding of first-year students’ perceptions of engineers and engineering. In addition, we counted how many students expressed similar sentiments in order to get a better feel for how common such perceptions were.

II. Findings

As previously discussed, all first-year West State students thought technical knowledge and skills like math and science were “very important” to “crucial” in becoming an engineer, with no significant gender difference. A difference began to emerge in the analysis of the “five terms” data, which suggested that men were somewhat more likely than women to offer math-science-logical terms, more likely to offer active-experiential terms, and somewhat less likely to offer creative-innovative terms. Another difference was that men were more likely than women to list terms from more than one category, suggesting that men look more broadly at engineering thinking than do women.

TABLE V
SKILLS IMPORTANT FOR ENGINEERS IDENTIFIED IN STRUCTURED INTERVIEWS, WEST STATE, (n = 29)

		Total	Female	Male
		29	12	17
Math-science-logical	count	23	9	14
	percent	79%	75%	82%
Creative-innovative	count	14	10	4
	percent	48%	83%	24%
Active-experiential	count	4	0	4
	percent	14%	0%	24%

Among other structured interview questions, students were asked, “Are there particular skills that you would say are important for an engineer to have?” Table V shows the number and proportion of women and men from West State who reflected on skills and abilities in each of the ways of thinking categories in response to this question. As indicated, a high proportion of both men and women reflected on math-science-logical skills and abilities, but women were more likely to discuss creative-innovative skills and abilities.

A broader look at the structured interview data provides an even more complex picture of gender differences. Almost all students at some point during their interview discussed

math and/or science abilities and interest as being important for engineering. For example, when asked how he felt about engineers, one male participant replied,

I'd say they normally have to be sort of at least more logical or more [left]-brain-oriented than most people. Uh they're definitely dealing with the sort of maths, the sciences a lot more than other people. So um, they definitely have to have a different perspective on things. They're probably not gonna do so well going into sort of other more um, I don't know, other sort of vocations [which] use more creativity and less logic... Engineering I feel has such a base in sort of mathematics and sciences. I feel like because it's got that strong base, you have to have that sort of fundamental understanding in order to succeed. Uh if you don't have the fundamental understanding of those kind of concepts you're gonna be a low-paid engineer.

A female participant had identified creativity as an important skill for engineers and said this was a skill that she had. When asked how she developed that skill, she responded,

I would have to say a lot of exploring. I guess I've always been interested in math and science and those subjects give a lot of critical thinking skills and so I've always been on the science end of, and that's what sciences and math do is to kind of skill you in those ways of, indirectly I guess.

This woman was typical of the students who saw a link between math-science-logical ways of thinking and creative-innovative ways of thinking, rather than approaching them dichotomously. Indeed, many students thought a diverse range of skills would be important for engineering. As one male student said, "[Engineers] would need to be logical, creative, have some sort of people skill and be technically minded." A female student said, "I think the work that [engineers] do is hard and takes a lot of brains in both, you know, practical aspects and creative aspects."

Some students saw math and science in contrast to creativity. For example, when asked how he felt about engineers, one man replied, "I don't see them as extremely creative, [rather] somewhat narrow-minded as set in their ways but also very knowledgeable about math and science." Another supposed, "Engineers are generally considered to be math/science people." Unfortunately, when asked about creativity in particular, several students did not perceive opportunities to be creative at this early stage of their education. As one young man said, "I'm just taking... chemistry, math and yeah and there is nothing to be creative about it, is just what it is."

Regardless of whether students thought math-science-logical thinking was a complement to or stood in contrast to creative-innovative thinking, most students acknowledged at some point in the interview the application of these kinds of thinking to real world practice. As one student put it when asked to define engineering, "I guess it'd be the application of theoretical math and science to real world situations." Although students of both genders described engineering as a field with real world application, men were more likely to have focused on hands-on activities: "I definitely like the sort of the tinkering aspect, uh the building things." Women were more likely to have focused on creativity and design for real

world application, "to design something, and see it come to life." As one woman explained, "It's like using creativity and ah innovations to find out new ways [to] do things more efficiently and design new things entirely."

When called upon to reflect more freely about engineers and engineering, first-year students revealed richer and more complex perspectives on engineering ways of thinking than when asked closed-ended quantitative or qualitative questions. The mixed analytical methods presented here both support one another and also provide nuanced insight into men's and women's perspectives of what kinds of thinking would be involved in the study and practice of engineering.

DISCUSSION

We have discussed what beginning students at West State perceive engineers and engineering to be all about. We suggest that these perceptions are reference points for students that contribute to their decision to select engineering over other disciplines. With our mixed-methods analysis, we found a complex picture of the knowledge, skills, and kinds of thinking students perceive are most required of engineers, and to some extent, we found suggestions of gendered differences.

All the data reflect that regardless of gender, the vast majority of first-year students view technical knowledge and skills including math, science, and similar abilities and ways of thinking as foundational to success in engineering. The qualitative datasets begin to reveal subtle differences between women and men. The "five terms" data show that, given a limited amount of freedom to formulate their answers, men seem to take a broader view than women of ways of thinking required in engineering. Furthermore, men are somewhat more likely than women to note math-science-logical ways of thinking and somewhat less likely to note creative-innovative ways of thinking. Also, men are more likely than women to mention active-experiential ways of thinking. Finally, the five terms data suggest a difference in how men and women value engineering for themselves and others.

The qualitative, structured interviews allowed students much greater latitude to reflect on their opinions about engineering. The data elicited in these interviews suggest that many students see links between the different ways of thinking; that is, math and science are foundations for creativity, and both math-science-logical thinking and creative-innovative thinking are foundations for active-experiential thinking. On the other hand, some students see math-science-logical thinking in opposition to creativity, especially in how they experience their first-year, math- and science-heavy, pre-engineering education.

There might be gender differences in how students view the practical nature of engineering as a field. Men were more likely to discuss and be attracted to the hands-on possibilities: tinkering, building, trying out ideas in the real world. Women were more likely to discuss and be attracted to linking theory and practice: designing and creating.

It is widely acknowledged that engineering requires all these diverse abilities and ways of thinking (and others not discussed here). However, these first-year women and men

had slightly different perceptions and interests, with men concentrated more on math-science-logical and hands-on experience, and women concentrated more on creativity-innovation and design experience. Yet, the dominant understanding of all students was that math and science abilities are of the highest importance, and the majority of students' first-year, preparatory education was centered on building these skills.

This complex picture suggests why women as a group may be less likely to be attracted to engineering study in the first place. Literature on men's and women's gender identity development provides evidence of the cultural association of physical science and scientific ways of thinking—reason, fact, objectivity—with males and masculinity. At the same time, feelings, values, and subjectivity are associated with females and femininity [14]. Using this lens, “male” ways of thinking seem to loom large in the minds of first-year students as they think about what engineering is and what it takes to be a successful engineer.

When first-year women and men were given latitude to brainstorm the kinds of skills they thought necessary for engineering, women were much less likely than men to cite active-experiential ways of knowing. This suggests that women generally have not had as much exposure as men to hands-on, engineering problem-solving prior to their entry into higher education. Again, this phenomenon may be the result of social norms about gender appropriate behavior.

Our study supports the claim that more first-year students and women in particular would choose engineering if they had a broader, more accurate understanding of the field [2][3][5]. K-12 outreach and recruitment strategies should emphasize the importance of creativity, design, and communication (as well as math and science) in the study of engineering. Furthermore, ensuring hands-on science, technology, and math opportunities for pre-college women may help them to better envision the active/experiential nature of engineering study and practice. Equally important, we might reexamine introductory engineering curricula and the extent to which they reinforce the narrow view of engineering reflected in our findings. (Drexel University's tDEC curriculum [15] aligns well with our recommendations but is atypical.) Ensuring that we recruit in good faith will ensure that we not only attract but also graduate a more diverse pool of talent.

Finally, with ongoing analysis of the wealth of longitudinal, multi-institution data from the APS and continued validation of the APS instruments, we intend to build on this study by integrating our analyses with data on how students approach and solve engineering problems in the performance task. We also plan to examine how these students' perspectives on engineering might change as they continue their studies, as well as the educational experiences that are related to the changes.

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