Young Women Exposed Actively to the Value of Biomedical Engineering

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***Abstract*—To bridge the gap between the biological sciences (typically female-dominated) and engineering (typically male-dominated), biomedical engineering (BME) activities could potentially be used as a vehicle to alter female students' perception of engineering as a whole. Female's pursuit of STEM (Science, Technology, Engineering and Math) degrees is typically confined to the biological sciences and females earn a high proportion of degrees in nursing, psychology and the social sciences, yet male presence persists in physical sciences and engineering. Female's participation in engineering remains much lower than men at all degree levels. Here, research questions included do female high school students: 1) perceive engineering as relevant? 2) have an interest & aptitude towards exploring engineering in college and as a career? 3) have anxiety in terms of engineering? 4) have engineering "role-confidence"? Participants, a randomly selected pool of 28 high school students (almost exclusively female from schools throughout the DC Metro area) took part in a week-long, all-day workshop where they were exposed to female engineering mentors, peers, and activities tied to BME & Engineering. Pre and post surveys, adapted from standard STEM surveys, were administered to the pool of participants. Increases in confidence and interest in engineering and decreased anxiety were observed following female high school students' participation in hands-on activities in BME.**

Clinical Relevance— There is a need to train and diversify the engineering workforce tied towards solving problems in human health. This educational research study was tied to this goal.

I. Introduction

Women's participation in engineering still remains much lower than men at all degree levels [1]. Female pursuit of STEM (Science, Technology, Engineering and Math) degrees are confined to the biological-related & social science- related fields however, male-dominance persists in the physical sciences and engineering [1]. Despite previous notions on male versus female math proficiency related to the pursuit of engineering, gender differences in average math achievement are insufficient to explain the substantial gender segregation in STEM fields or occupations [2, 3]. Female's attitudes and perception of subfields within STEM field (e.g., biological science as opposed to engineering) is important to understanding the gender, and ethnic, gap in engineering. In addition to discriminatory and cultural factors [4] and chilly climates [5], social psychological factors (e.g., related to self-assessment, perception and confidence) of females pertaining to engineering must be further investigated [6]. The contribution of gender differences, social control, role models, and experiential learning has to be systematically examined.

To date (still), little is known about how race, ethnicity, and gender are tied to self-confidence in STEM. The underrepresented minority (URM) groups within the United States workforce is expected to increase from 25% to 50% by 2050 [7], however, URMs receive fewer engineering degrees than White males. Research focused on attracting and retaining diverse populations in engineering is critical.

Litzer et al. [7] utilized social-cognitive theory for investigating academic confidence in STEM tied to ethnicity and gender, and it was observed that some underrepresented groups may have lower STEM confidence than White males, overall. Cech et al. [6] stated that engineering is the most sex-segregated nonmilitary profession in the United States. Since the mid- 1990s, engineering displays a prevalent gender disparity in that women have been earning fewer degrees in engineering [8, 9], thus leading to the subsequent lack of females in the engineering workforce [10-13]. Because undergraduate engineering programs are male-dominated, studies have sought to identify discrepancies in female satisfaction with pursuing an engineering major and desire to enter the engineering workforce [14-16].

In general, science content, especially in the physical sciences, may be scoped to not have as great a relevancy to real-life experiences for girls as it does for boys. However, increased opportunities for ''tinkering'' with science equipment during childhood would likely benefit girls (as suggested by [17]). As adolescents, boys are more likely than girls to participate in tinkering and gaming activities [6,18]; these activities can serve as a form of preparatory socialization to skills needed for engineering [19, 20]. Less exposure to this anticipatory socialization leads to increased difficulty developing the expertise and confidence necessary for engineering success. Unfortunately, long before entering college, young women are being turned off to the idea of engineering. A report by Hill et. al [21] of the American Association of University Women (AAUW) summarized meaningful research and their outcomes. In particular, within [21], it had shown that environment and culture around girls influences their self- assessment and, activities should be targeted towards improving spatial skills (e.g., encourage youths to engage with construction toys and kits, take things apart, build things, draw and engage in hands-on activities).

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During students' education, experiential learning opportunities strongly influence their future career pathways and persistence in engineering [24-26], as well as exposure to role models. Female URM youths, early in their academic/ professional careers must be exposed and encouraged to pursue engineering.

Our project personnel aimed to extend high school curricula via the young Women Exposed Actively to the Value of Engineering (WEAVE) Summer Program, to nurture teamwork, critical-thinking, and problem-solving [27] by designs and devices that will aid individuals suffering from mobility-related disabilities, as well as exposure to (engineering) equipment used towards these areas. Expectations for success relate directly to a one's self-concept and ability [28]. Self-confidence and self-efficacy influence academic achievement; self-efficacy is directly tied to one's beliefs in their capacity to fulfill certain tasks and goals. Youths who perceive themselves as having high efficacy (e.g., via positive, hands-on Biomedical Engineering (BME) project experiences) will perform well academically, have high educational aspirations and feel capable of pursuing careers in engineering [29, 30]. As a result of the WEAVE activities, it was hypothesized increased interest in female high school URMs to pursue BS degrees in BME, or engineering in general.

II. Methods

The University of the District of Columbia (UDC) based in Washington, DC has a significant role to play in understanding the engineering gender, as well as ethnic, gaps. UDC's unique and distinctive ecosystem make it conducive to educational research and understanding where (and how) improvements can be made. Historically Black Colleges and Universities (HBCUs) comprise < 3% of colleges and universities nationwide, yet they still graduate approximately 33% of African American Bachelor of Science (BS) degree holders in Science and Engineering [22]. UDC is an HBCU, the only public institute of higher education in our Nation's capital, and has a predominantly female student demographic, many of whom are URMs. Of the 100+ HBCUs nationwide, UDC is only one of few which offers a BS in Biomedical Engineering (or BME). UDC's climate and mission make it poised to serve as a critical component to understanding and enhancing the diversity of the engineering workforce and BME is an attractive vehicle for this integration. BME is a relatively new, multidisciplinary field that integrates engineering concepts to solve problems in human health. At UDC, by providing exposure and mentorship within a field that is at the intersection of biology, medicine & engineering, we are hypothesizing that female URMs may have an altered, but enlightened and illuminated, perception of engineering via this new BME field.

The percentage of women is higher in BME than in many other engineering fields [23]. BME is a unique field, that holds appeal to women and URMs in that it is more interconnected with biological & medical sciences than other engineering fields. Although gender diversity is low in engineering overall, BME has been shown to attract women at undergraduate & graduate levels, higher than any other engineering discipline [23]. Increasing the number of female youths that seek to obtain undergraduate engineering degrees is a critical step. The approach within this paper was to utilize BME as a vehicle to gain female youths' interest in engineering overall.

All activities were conducted within the UDC Center for Biomechanical & Rehabilitation Engineering (CBRE) and the Machine Shop at the UDC. For this educational research activity, the protocol was approved by the UDC Institutional Review Board (974777-1). Prior to taking part in this educational research activity, informed consent and informed assent were obtained. The workshop was advertised via flyers posted on school message & newsletters; interested parents & high school counselors also shared the information on Twitter and other social media.

A. Participants & Workshop Activities

The 4-day, all-day WEAVE Summer Program had 28 ((24 females: 15.8 years old +/- 1.1 years; 4 males: 16.3 years old +/- 1.5 years old) participants from 9 high schools spanning the DC Metro area. Of the 28 student participants, 4 female students opted out of the post-surveys. However, the results will describe findings for 24 participants that completed the pre-post surveys: 20 females and 4 male participants.

Participation in BME activities, as discussed here, for students (almost exclusively female URMs, in grades 9 – 12) was targeted to help project participants enhance their self-confidence, particularly in engineering. This may create the appropriate climate to evoke active, perceptual and behavioral changes of female URMs towards engineering pursuit.

This WEAVE Summer Program provided an excellent opportunity for the lead investigators (both female, ethnic minorities, and engineering professors), to serve as positive role models to WEAVE participants. Further, the WEAVE Summer Program provided hands-on, exposure for DC area high school female URMs to problem-solving through hands-on kits in BME (e.g., robotics for rehabilitation, research-grade motion capture and forceplate equipment, rovers, solar robots, and others). More specifically, BME-related activities involved the following: design & construction of a lower limb prosthetic and a bionic robotic hand; hands-on exposure to research-grade instrumentation within the CBRE lab, used towards investigating human balance & mobility (e.g, Tekscan Forceplate Walkway, NaviGAITor partial body-weight support system, Vicon Motion Capture, Surface Electromyography (sEMG), HTC Vive Virtual Reality, Open Bionics Robotic Hand); field trip to the National Museum of Health and Medicine (to observe human & brain specimens, as well as the progression of prosthetics throughout the past 200+ years). Other engineering project activities included: rover constructions and exposure to electric circuits; building solar-powered robots; constructing air-powered race cars. At the conclusion of the workshop, each participant received a certificate.

B. Measurement Tools: Pre/Post Surveys

In order to gauge changes in interest-level, surveys were administered both pre and post; each student was blind to their initial responses. Student participants completed an "Interest in Pursuing Engineering" survey; this survey was adapted from "Persisting in Engineering Survey v1.0" (AWE 2007 [31]). Within the "Interest in Pursuing Engineering" survey,

questions included for example: "How interested are you in pursuing a college degree (in engineering)?" and "How confident are you that you will complete a college degree (in any major)?" Student participants also completed both a pre and post workshop an "Attitudes & Motivation Toward Engineering Inventory". This survey was adapted from "Attitudes toward mathematics inventory", Martha Tapia 1996 [32] and "Science Motivation Questionnaire II", Shawn M. Glynn 2011 [33]). Within the "Attitudes & Motivation Toward Engineering Inventory" survey, phrases fell under the umbrella of the following in terms, tied to Engineering: Relevance, Interest & Aptitude, Negative Feelings/Comfort, and Confidence. However, the participants were unaware in that the targeted phrases were randomized throughout the survey. Some example phrases were: "Studying engineering makes me feel nervous"; "The challenge of engineering intimidates me"; "I really like engineering", and many others. For each phrase, based on a Likert-type scale, the students had to select: 1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree, or 5 – strongly agree. Pooled results (mean) for computed for each of the areas, both pre- & post, in order to determine if there were attitudinal changes. Further, a percentage difference was then computed for each pre/post response to each phrase.

Self-report was meaningful in that the participants were reporting about their beliefs, attitudes and perceptions about engineering which was exactly what was intended to measure. Further, survey response measures were streamlined, inexpensive, and easy to obtain. Disadvantages could be, for example: conscious, or unconscious, influences in terms of social acceptability, rather than honesty; inability to assess one's self accurately. However, in terms of ratings, a broad range of response options to the participants. In terms of biases, participants were blind to their pre-responses when completing their post assessments. Combining self-report data with other information, such as behavioral or psychological data, was not possible for the current study.

III. Results

A. Demographics

The WEAVE Summer Program participant demographics were 86% female and 14% were male. It was interesting that, although the WEAVE activity was predominately meant to target female URMs and advertised as such, male participants were still interested in taking part, regardless that both program mentors were female URMs and there would likely be mainly female students participating. Further, the male participants were predominantly White. Female participants were predominantly African American (50%), followed by White (29%), Hispanic (13%) and Asian (9%) participants.

B. Interest in Pursuing Engineering

The "Interest in Pursuing Engineering" survey probed interest in pursuing a college degree and interest in engineering, specifically. All participants responded that they had plans to go to college. Five female participants wanted to go to college but were undecided and three female participants wanted to go to college, then work in industry; the others did not describe future plans, other than aspiring to go to college. For the male participants, aside from going to college, one participant wanted to start their own business, and two others had aspirations to work in industry. In terms of confidence completing a college degree, 18 of the female participants were "very confident" (both pre- & post), and 2 shifted from "neutral" or "somewhat confident" (pre-workshop) to "confident" or "very confident "(post-workshop).

The survey also inquired interest in pursuing, specifically, an engineering college degree. For the female participants, comparing pre- & post, there were 6 changes towards pursuing engineering: 3 changes from "neutral "to "interested"; 2 changes from "not interested" to "neutral" and 1 change from "not interested" to "interested". On the other hand, there were 2 changes from "neutral" to "not interested." Of the four male participants, in comparing pre- & post, there was one change from "interested" to "very interested" in pursuing engineering; there were no changes away from pursuing engineering. For the remaining participants, they were already interested in engineering or were neutral and remained as such in comparing pre- & post: 7 (total) remained at "interested" or "very interested" and 5 (total) remained "neutral."

The survey further asked the question if the WEAVE program increased their interest in engineering overall. Of the 20 female participants that completed the pre- & post surveys, over half (16 students) positively responded: 11 replied as "yes" a definite impact & 5 replied as "moderate" impact. On the other hand, 4 said that there was "no impact" in their interest, and 1 did not respond; however, it is of note that those that said no impact, had already expressed an interest in engineering at onset. Of the 4 male participants that completed the pre- & post surveys, half (2 students) responded "yes" a definite impact and 2 replied as the workshop having a "moderate" impact on them.

Lastly, the survey inquired about favorite parts of the workshop; students could indicate (select) more than one area. For the 20 female participants that completed the survey, 18 (nearly all) participants enjoyed the projects; 6 enjoyed the mentorship; interestingly, half (10 students) stated they enjoyed bonding with peers. For the 4 male participants that completed the survey, 1 enjoyed the mentorship, half (2 students) indicated bonding with peers and 2 indicated projects.

C. Attitudes & Motivation Toward Engineering

The "Attitudes & Motivation Toward Engineering Inventory" posed a series of questions that were randomized throughout the survey and addressed the participants' viewpoints of Engineering in terms of the following: Relevance, Interest & Aptitude, Negative Feelings/Comfort, and Confidence. Pooled responses for male and female participants, as well as the % difference, pre- & post workshop are shown in Table 1.

In terms of "Relevance", participants (both male and female) were able to see the utility of engineering both pre & post, therefore, there were not large changes in perceptions. However, for the male participants, there was a 20 % increase

post on the response to "I can think of many ways that I use engineering outside of school."

Table 1. Pooled responses for female & male participants pre - & post WEAVE workshop (1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree, or 5 – strongly agree); Percent (%) difference between pre- & post shown.

		Female		Male		% Difference	
		Pre	Post	Pre	Post	*Female*	*Male*
Relevance	Engineering is very worthwhile and necessary.	4.3	4.5	4.5	4.8	5.9	5.6
	Engineering helps develop the mind and teaches a person to think.	4.2	4.3	4.5	4.8	2.0	5.6
	Engineering is important in everyday life.	4.0	4.3	4.5	4.5	5.2	0.0
	Learning about engineering will help me to get a good job.	3.8	4.0	4.0	4.3	6.6	6.3
	Building my engineering skills will benefit me and my career.	3.8	4.0	4.0	4.3	5.5	6.3
	I can think of many ways that I use engineering outside of school.	3.4	3.7	3.8	4.5	8.5	20.0
	I think studying engineering would be useful.	4.0	3.8	4.5	4.8	-4.2	5.6
	A strong background in engineering could help me in my professional life.	3.8	4.1	4.5	4.8	6.5	5.6
Interest/Aptitude	I want to develop my engineering skills.	3.8	4.0	4.5	4.3	6.6	-5.6
	I get a great deal of satisfaction out of solving engineering problems.	3.3	4.0	4.3	4.5	21.5	5.9
	I would like to avoid engineering in college.	2.4	2.5	3.0	2.3	5.2	-25.0
	I really like engineering.	3.3	3.7	4.0	4.8	11.4	18.8
	The challenge of engineering appeals to me.	3.5	3.5	3.3	3.8	-1.2	15.4
	The challenge of engineering intimidates me.	3.0	2.5	3.7	2.7	-17.1	-27.3
Negativity/Comfort	Studying engineering makes me feel nervous.	2.7	2.1	2.3	1.8	-20.3	-22.2
	Engineering makes me feel uncomfortable.	2.0	1.8	1.3	1.3	-10.2	0.0
	I have anxiety when I even think about engineering.	1.8	1.9	1.3	1.3	7.1	0.0
	I dislike learning about engineering.	2.1	2.1	2.0	2.3	0.0	12.5
	Engineering does not intimidate me at all.	3.0	3.0	3.3	3.3	-1.4	2.6
	I feel confused about engineering.	2.7	2.5	2.3	2.0	-6.2	-11.1
	I feel insecure about solving engineering problems.	2.6	2.3	2.0	2.0	-9.0	0.0
	I am comfortable expressing my own ideas & how to seek solutions to a difficult (engineering) problem.	3.5	4.0	4.0	4.5	14.3	12.5
Confidence	I learn problem-solving skills easily.	3.6	3.8	3.5	4.0	5.8	14.3
	I am confident that I could learn engineering skills.	4.0	3.8	3.3	3.8	-4.2	15.4
	I have a lot of self-confidence when it comes to engineering.	2.7	3.2	3.3	4.0	18.5	23.1
	I am able to solve engineering-type problems without much difficulty.	2.8	3.3	3.3	3.8	17.9	15.4
	I expect to do fairly well if I decide to pursue engineering as a career.	3.3	3.5	3.8	3.8	6.2	0.0
	I believe that I have good engineering skills/traits.	3.5	3.7	4.3	4.3	6.9	0.0

In terms of "Interest & Aptitude", to the phrase "I get a great deal of satisfaction out of solving engineering problems", female students showed 21.5% increase towards strongly agreeing with this statement, while male students already agreed/strongly agreed with this statement. To the phrase "I would like to avoid engineering in college", there was a 25% decrease in the male participants' response (meaning that they were shifting towards strongly disagreeing with this statement). To the phrase, "I really like engineering" females had an increase of 11.4% and males an increase of 18.8%. To the phrase "The challenge of engineering intimidates me", females showed a decrease of 17% and males a decrease of 27%.

In terms of "Negativity/Comfort" towards Engineering, to the phrase "Studying engineering makes me feel nervous", females showed a decrease of 20.3% and males 22.2%. To the phrase, "Engineering makes me feel uncomfortable", female students showed a 10.2% decrease while male student exhibited no change. To the phrase "I am comfortable expressing my own ideas & how to seek solutions to a difficult (engineering) problem", females showed a 14.3% increase and males showed a 12.5% increase. Other changes were decreases in confusion about engineering.

In terms of "Confidence", to the phrase "I have a lot of self-confidence when it comes to engineering", both female and males showed increases of 18.5 and 23.1%, respectively. To the phrase, "I am able to solve engineering-type problems without much difficulty", there were increases for both female and male participants of 17.9 and 15.4%, respectively.

IV. Conclusion

By conducting a week-long engineering exposure workshop focusing on BME, positive shifts in interest, comfort, and confidence towards engineering were observed in female participants, but surprisingly, male participants as well. In the surveys, it was determined projects impacted (enhanced) interest levels in engineering, however interestingly, bonding with peers for both males and females (being able to surround yourself with peers working on similar tasks/projects), and perhaps the integration of female mentors, had a positive influence. Aside from exposure (via the WEAVE workshop), training should also take place as a continuation towards 'moving the needle'. However, the first step (among) many steps, was to ignite interest, modify misperceptions, and enhance confidence via hands-on exposure tied to BME which the WEAVE workshop accomplished.

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