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Liberal Studies in Engineering Programs – Creating Space for Emergent & Individualized Pathways to Success for Women in Computing Disciplines

Dr. Jane L. Lehr, California Polytechnic State University, San Luis Obispo

Jane Lehr is Chair of the Women's & Gender Studies Department at California Polytechnic State University, San Luis Obispo. She is also an Associate Professor in Ethnic Studies, Director of the Science, Technology & Society Minor Programs, and Faculty Director of the Louis Stokes Alliance for Minority and Underrepresented Student Participation in STEM Program at Cal Poly. She previously served as elected co-chair of the Science & Technology Taskforce of the National Women's Studies Association, and as a Postdoctoral Research Officer at the Centre for Informal Learning and Schools (CILS) at King's College, University of London. Her graduate training is in Science & Technology Studies and Women's Studies at Virginia Tech.

Dr. Michael Haungs, California Polytechnic State University

Michael Haungs is an Assistant Professor in the Computer Science Department at California Polytechnic State University. He received his B.S. degree in Industrial Engineering and Operations Research from the University of California, Berkeley, his M.S. degree in Computer Science from Clemson University, and his Ph.D in Computer Science from the University of California, Davis. Dr. Haungs specializes in game design, web development, and cloud computing. He is the developer of PolyXpress (http://mhaungs.github.io/PolyXpress) – a system that allows for the writing and sharing of location-based stories. Dr. Haungs has also been actively involved in curriculum development and undergraduate education. Through industry sponsorship, he has led several K-12 outreach programs to inform and inspire both students and teachers about opportunities in computer science. Recently, Dr. Haungs took on the position of Co-Director of the Liberal Arts and Engineering Studies (LAES) program. LAES is a new, multidiscisplinary degree offered jointly by the College of Liberal Arts and the College of Engineering at Cal Poly.

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Abstract

Today, an increasing number of women enter, remain, and succeed within science, technology, engineering, and mathematical (STEM) fields. However, women's participation is still not proportionate. Women earned 18.4% of undergraduate degrees in engineering in 2010 according to the 2013 *Women, Minorities, and Persons with Disabilities in Science and Engineering* report published by the NSF, with significant variance by subfield.[1] The proportion of women graduating with a bachelor's degree in computing disciplines has decreased. [1] In 2012, the U.S. Congress Joint Economic Committee affirmed that, "Women's increased participation in the STEM workforce is essential to alleviating the shortage of STEM workers" in the United States.[2] The ASEE Diversity Task Force has identified increasing the percentage of undergraduate female students to 25% by 2020 as a strategic goal.[3] Explanations for the continued underrepresentation of women include the impacts of the social structures of society, education and the professions on women's participation, as well as the content and application of STEM knowledge in these disciplines. While many challenges to recruitment and retention are shared, Roberts, Kassianidou and Irani (2002) suggest that there are "more specific problems that seem unique to or particularly pronounced" in computing disciplines, including huge variance in pre-college computing experience by gender and the ease in which social biases can be incorporated into the design of computing systems (p. 85).[4]

However, transformative models for changing the face of engineering and of computing disciplines, specifically, already exist. This paper describes and analyzes one such model – an innovative "liberal studies in engineering" (LSE) program at a large state university in California, Comprehensive Polytechnic State University (CPSU). Jointly offered by the Colleges of Liberal Arts and Engineering, LSE is understood as a fourth "computing discipline" by the Department of Computer Science (alongside computer engineering, computer science, and software engineering). Admission to the program is by internal transfer only. Accepted students complete rigorous technical education, including 44 units of support courses shared with the College of Engineering as well as the CPSU General Education curriculum; 34-35 units of additional coursework in an engineering specialization (computer graphics OR electrical engineering (power) OR industrial/manufacturing engineering (systems design) OR an individualized course of study); 24 units of additional coursework in a liberal arts specialization; and at least 4 LSE courses: two on project-based learning, a senior project course, and a capstone.

As of Fall 2014, over 34.5% of the 55 LSE total graduates are women. Eighteen of these 55 alumni graduated with an engineering concentration that included at least 4 quarters of the introductory computer science sequence (CSC 123, 101, 102, and 103) – and thus, for the purposes of this paper, function as a comparison group to the computing disciplines at CPSU and nationally. Of these eighteen LSE-computing disciplines alumni, seven, or 38.9%, are women.

Why this difference? One explanation is that LSE is a small major with a high level of one-on-one advising. However, a high degree of flexibility also contributes. In the LSE program,

iterative revision and recreation of an individualized curriculum and career plan are understood as signs of success rather than failure or deviation. Students are encouraged to understand and design their major as a "whole-person technical degree" that does not require them to pass, to assimilate, to compartmentalize, or to conform to stereotypes. We suggest that this holistic flexibility may disrupt barriers such as impostor syndrome by positioning the student not as impostor but as designer and creator – even when enrolled in technical courses in which the sex/gender ratio is skewed male. Lessons learned from "liberal studies in engineering" are identified, as well as sites of further research.

Introduction

In 2012, the U.S. Congress Joint Economic Committee affirmed that, "Women's increased participation in the STEM workforce is essential to alleviating the shortage of STEM workers" in the United States.[2] The ASEE Diversity Task Force has identified increasing the percentage of undergraduate female students to 25% by 2020 as a strategic goal.[3] Today, an increasing number of women enter, remain, and succeed within science, technology, engineering, and mathematical (STEM) fields. However, women's participation is still not proportionate. In fact, while the proportion of women earning masters and doctoral level degrees has increased in engineering, the proportion of women earning bachelor's degrees has not.

Women earned 18.4% of undergraduate degrees in engineering in 2010 according to the 2013 *Women, Minorities, and Persons with Disabilities in Science and Engineering* report published by the NSF, with significant variance by subfield.[1] National data for bachelor's degrees awarded to women by discipline is published in the 2013 edition of the Profiles of Engineering and Engineering Technology Colleges by ASEE (Figure 1). This data shows that undergraduate engineering is impacted by patterns of territorial segregation, with high rates of bachelor's degrees awarded to women in Environmental Engineering (45.8%), Biomedical Engineering (38.9%), Chemical Engineering (32.3%), and Biological & Agricultural Engineering (32.0%), and low rates in Aerospace Engineering (14.5%), Electrical Engineering (14.0%), Computer Science (inside engineering) (13.0%), Computer Science (outside engineering) (13.0%), Mechanical Engineering (12.5%), Electrical/Computer Engineering (12.3%), Mining Engineering (12.1%), and Computer Engineering (10.7%).

The proportion of women graduating with a bachelor's degree in computing disciplines has decreased from 15,668 in 2003 to 8,730 in 2012 (a 44% decrease) while the rate of men earning a bachelor's degree in computer science has only decreased by 17% (to 47,960 in 2012).[1] While many challenges to recruitment and retention are shared between computing disciplines and (other) engineering fields, Roberts, Kassianidou and Irani (2002) suggest that there are "more specific problems that seem unique to or particularly pronounced" in computing disciplines, including huge variance in pre-college computing experience by gender and the ease in which social biases can be incorporated into the design of computing systems (p. 85).[4] In January 2014, headlines such as, "Not One Girl Took The AP Computer Science Test In Some States"[5] and "No Girls, Blacks, or Hispanics Take AP Computer Science Exam in Some States"[6] proliferated after College Board data was released about the approximately 31,000 students who took the AP exam in Computer Science in 2013 – less than 20% of which were female students. Of the

graduating class of 2013, only 19% of test-takers were female, 4.2% were Black or African American, and 9% were Hispanic or Latino/a[7]

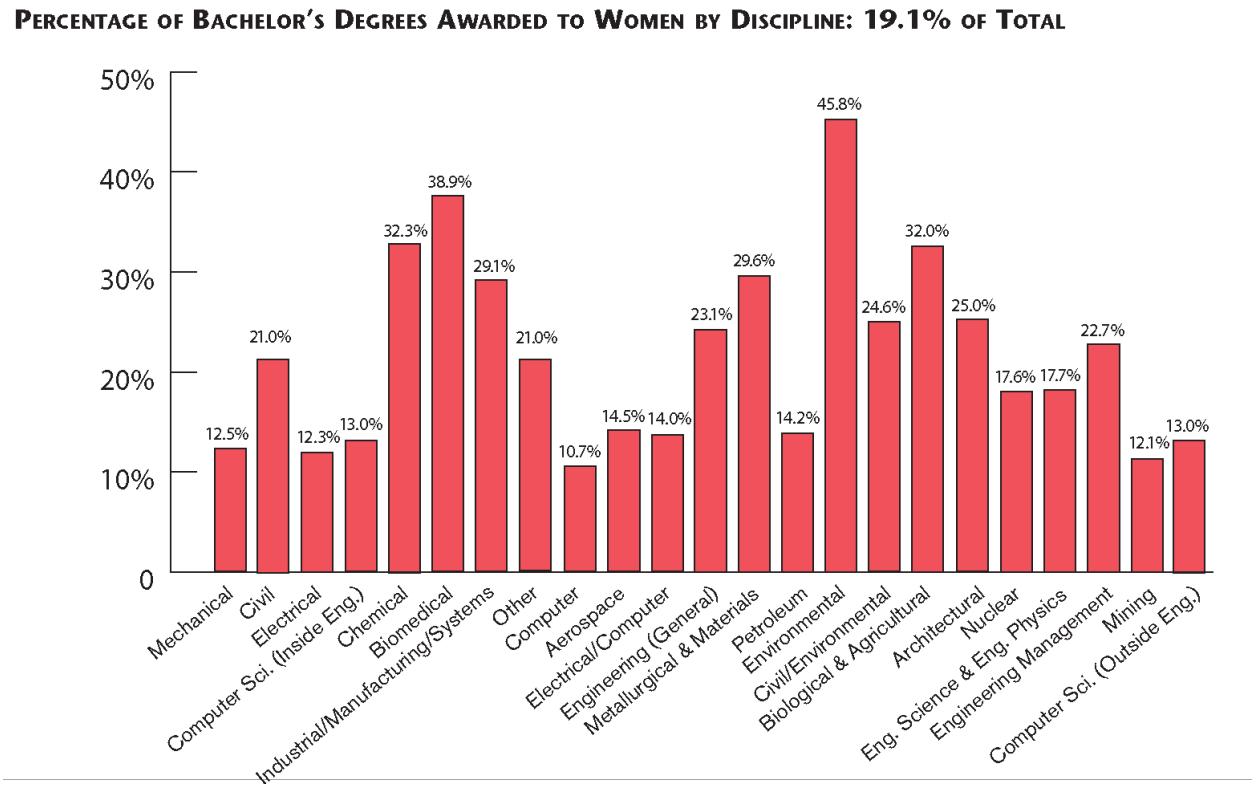

Figure 1: Percentage of Bachelor's Degrees Awarded to Women by Discipline (ASEE, 2013)

Explanations for the Status of Women in STEM Today

Contemporary explanations for continued underrepresentation can largely be grouped into two categories: 1) the social structure of society and 2) the social structure of STEM education and professions. For example, researchers focused on the social structure of society have highlighted the important role of early play experiences in shaping feelings of efficacy and interest in STEM disciplines. Those focused on the social structure of STEM education and professions have focused on topics ranging from analysis of textbooks for images of scientists and classroom interactions for gender bias, to study of the tenure-track vs. baby-track phenomena.[8, 9] Within Computer Science, in particular, disparities in video-game playing and software/hardware tinkering, as well perceptions of and experiences in computer science (from nerd culture to 'brogrammer' culture).[10, 11]

Specific proposals for addressing the continued underrepresentation of women in STEM fields vary depending upon the age group targeted and the explanation adopted. The AAUW's 2010 report, *Why So Few? Women in Science, Technology, Engineering and Mathematics*, combines attention to the social structure of society and the social structure of STEM education and professions in its recommendations, seeking to address the impacts of stereotypes and implicit bias on both individual female students and the social, educational, and professional norms in

STEM disciplines. For example, the report focuses on mechanisms to reduce stereotype threat and identify implicit biases, and also addresses how changing student understandings of intelligence and spatial skills to emphasize that these skills can be learned leads to improved student performance. The report also points to research suggesting that the inclusion of real-world applications in coursework increases the retention of female students and calls for changes to the tenure, promotion, and mentoring systems in place at universities in the United States.[12]

The Status of Women in Engineering and Computing Disciplines at CPSU

At Comprehensive Polytechnic State University (CPSU), the number and percentage of women in engineering varies from major to major (Figure 2). In Fall 2013, the CPSU incoming cohort had the following majors with the highest proportions of female students: Environmental Engineering (57%), Biomedical Engineering (49%), Architectural Engineering (46%), Industrial Engineering (29%), and Civil Engineering (28%). Those majors with the smallest percentage of female students as incoming students in Fall 2013 were Mechanical Engineering (16%), Aerospace Engineering (15%), Electrical Engineering (15%), and Computer Engineering (14%), This data generally follows the national trends with some areas where CPSU exceeds the national data for percent female (AERO, ARCE, BMED, CE, CPE, CSC, EE, ENVE, GENE, and ME) and some areas where more women are present in a discipline nationally than at CPSU (BRAE, IE/MFGE, and MATE).

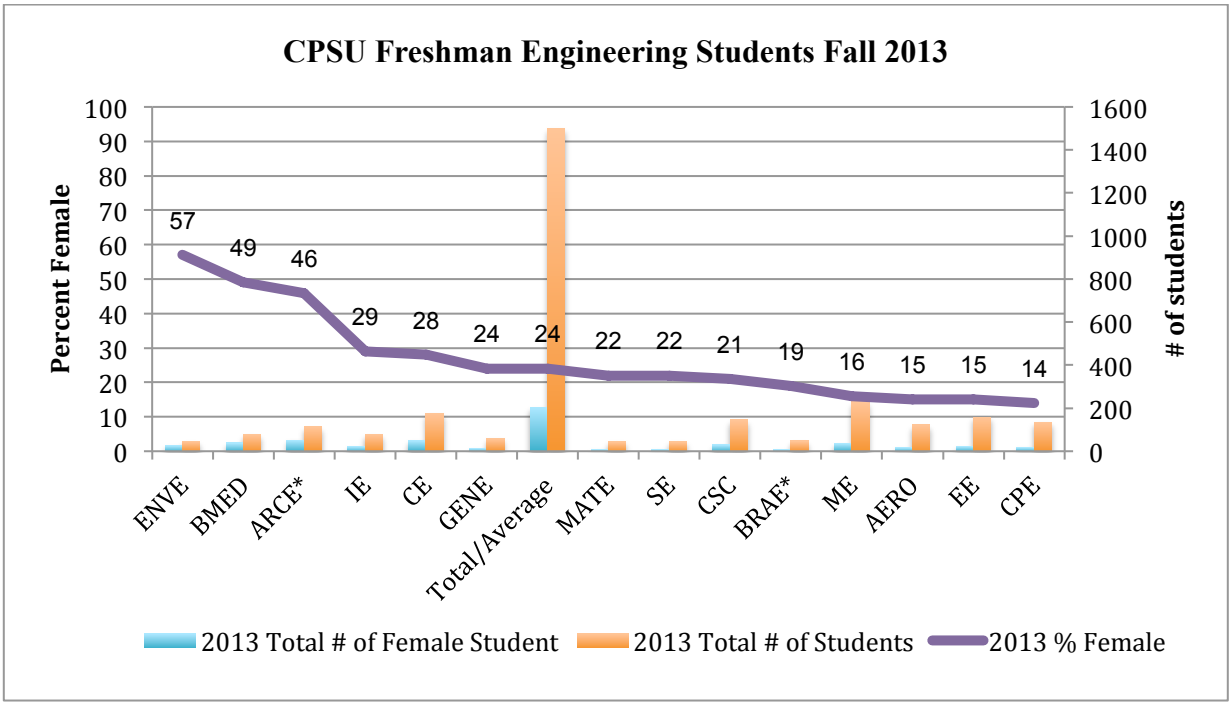

Figure 2: CPSU Freshman Engineering Students Fall 2013

The female students who enroll in engineering at CPSU and are retained within the college tend to do as well or better than their male peers. For example, grade frequencies data from 2008-09, 2009-10, and 2010-11 for the College of Engineering show that the average and weighted average grades for female students is higher than those for male students each academic year. The five-year graduation rates for cohorts of students who matriculated to CPSU in 2000-08

show that female students graduated at a higher rate than their male peers for each cohort (Table 1).

Table 1: 5 year graduation rates for incoming students, CPSU College of Engineering, 2000-08

	Fall 2000	Fall 2001	Fall 2002	Fall 2003	Fall 2004	Fall 2005	Fall 2006	Fall 2007	Fall 2008
Men	40.9%	43.4%	49.5%	47.0%	44.3%	45.3%	47.7%	42.1%	54.3%
Women	46.4%	53.3%	58.9%	64.7%	57.9%	60.6%	55.1%	50.9%	63.8%

Between the 2004-05 academic year and 2012-13, women made up between 13.0-16.7% of each graduating class at the bachelor's degree level. This is lower than the 18.4% national rate of bachelor's degrees in engineering earned by women in 2009-10, which does not take into account variations in distribution of students in the different engineering disciplines.

As visible in Figure 2, comparison of incoming freshman shows increases in the proportion of women between 2010 and 2013 in Architectural Engineering, Biomedical Engineering, Computer Engineering, Computer Science, Electrical Engineering, Environmental Engineering, General Engineering, and Software Engineering. Additional detail regarding the computing disciplines at CPSU is provided in Table 2. Students interested in computing declare one of three majors at CPSU at the time of application: Computer Science (CSC), Software Engineering (SE) or Computer Engineering (CPE). White it is true that in smaller majors, the addition of a small number of female students recruited can significantly impact proportions, we believe that the increase of women entering as majors in the computing disciplines at CPSU is correlated with recent efforts to change recruiting cultures and methods at CPSU, both across the College of Engineering (CENG) and, in particular, in the computing disciplines. That said, it is still unclear whether this increase in recruitment will result in an increase in retention and graduation way.

Table 2: Incoming Students in Computer Disciplines at CPSU, 2010-2013, by sex/gender

female student population	**2010 total students**	**% females**	**2011 total students**	**% females**	**2012 total students**	**% females**	**2013 total students**	**% females**
CSC	77	9%	153	12%	128	13%	146	21%
SE	34	13%	21	33%	43	9%	45	22%
CPE	82	9%	139	17%	135	13%	135	14%
CENG Average	998	17%	1405	21%	1292	21%	1339	22%

The proportion of female students who are retained and graduate from the computing disciplines at CPSU is substantially lower than the proportion of incoming students. For example, four years later, the adjusted cohort of students in Computer Science for Fall 2005 first-time students (that is, those students who entered in Fall 2005 and either graduated within 4 years or were still enrolled in the program 4 years later) was 1.9%. It was 5.3% for Fall 2006 first-time students, 6.9% for Fall 2007 first-time students, 9.4% for Fall 2008 first-time students, 8.9% for Fall 2009 first-time students, and 10.1% for Fall 2010 first-time students. If in 2016-17, the proportion of female students in Computer Science is closer to 21%, this will be a victory. However, even if CPSU graduates 21% women in Computer Science (CSC) in 2017 – matching the 2013

incoming class – the "problem" of women in computer science will not be resolved at CPSU or elsewhere. A more transformative solution is required.

Liberal Studies in Engineering (LSE) Programs – A More Transformative Solution?

In this paper, we draw from data and observations to suggest that "liberal studies in engineering" (LSE) programs may function as one site for transformative change within the computing disciplines (and other arenas of engineering) – and to identify LSE programs as an important site of research for those interested in increasing the number of women in Computer Science. As described by Bucciarelli and Drew in a forthcoming paper in *Engineering Studies* and at a January 2015 workshop at the National Academy of Engineering, the core idea of B.A. programs in "liberal studies in engineering" like that at CPSU is to "take exemplary, substantive content of the traditional undergraduate engineering program – the engineering sciences, the laboratory tests, the design projects – and subject this to study from the perspectives of the humanities, arts, and social sciences as well as engineering. The method is to build on the content and form of instruction in today's engineering program but dramatically transform both content and form to achieve the goals of a liberal arts program while attending to the fundamentals of the traditional engineering course of study."[13] As Bucciarelli and Drew further describe, "[t]o do this, 'fundamentals' must necessarily be redefined."

The B.A. Program in "liberal studies in engineering" (LSE) at CPSU is jointly offered by the Colleges of Liberal Arts and Engineering and is designed to prepare students for a wide-range of innovative careers in emerging professional fields that combine skills and interests in the arts, technology, and culture, and for study in diverse graduate disciplines. Unlike other majors at CPSU that students declare as part of their application to CPSU, admission to the program is by internal transfer only. Selection for enrollment requires a lengthy interview process designed to assess a student's maturity, responsibility, self-direction, organization, and ability to work well as an individual and as a member of team, including in high-stress situations. The LSE program at CPSU functioned in pilot status for 5 years, and became an official part of the CPSU curriculum in 2012.

Accepted students complete rigorous technical education, including 44 units of support courses shared with the College of Engineering (primarily drawn from the first- and second-year CENG curriculum) as well as the CPSU General Education curriculum; 34-35 units of additional coursework in an engineering specialization (computer graphics OR electrical engineering (power) OR industrial/manufacturing engineering (systems design) OR an individualized course of study) (at least 8 units at the 300- or 400-level); 24 units of additional coursework in a liberal arts specialization; and at least 4 upper-level LSE courses: two on project-based learning, a senior project course, and a capstone. Students must also either study or intern abroad, or complete 2 additional upper-level courses in global studies.

As of Fall 2014, 55 students have graduated with a B.A. in LSE at CPSU, and 55 additional students are currently active in the program (48 as LAES majors and 7 currently on a one- or two-quarter individualized change of major agreement). (Two other students were denied their degree in Spring 2012, 3 students discontinued the program, and 1 student has completed all of his requirements aside from components of his senior project.) A total of 116 students have been

involved in the LSE program. Nineteen of the 55 LSE graduates are women (34.5%). Female students had a 4-year graduation rate of 26.3% and a 5-year graduation rate of 100%. Of the male students who enrolled at Cal Poly as first-time freshman (33 of 36), the 4-year graduation rate is 21.1%, and the 5-year graduation rate is 72.7%. The average GPA for female graduates is 3.069 and for male graduates is 2.959.

By college, 80% of LSE students are internal transfers from the College of Engineering, but a growing number of students are transferring into the LSE program from other colleges – only 38.1% (21) of current students transferred into LAES from the College of Engineering compared to 21.8% (12) from the College of Liberal Arts and 18.1% (10) from the College of Science & Mathematics. Female students make up 30.8% of the transfers from the College of Engineering and 40% of transfers from the College of Liberal Arts (see Figure 3).

LSE at CPSU is understood as a fourth "computing discipline" by the Department of Computer Science (alongside computer engineering, computer science, and software engineering) – what this means is that LSE students completing a "computer graphics" or related individually designed engineering concentration are treated as "computing discipline" students in course registration algorithms and by "computing discipline" faculty and peers. Indeed, the LSE "computer graphics" concentration is one course short of a minor in Computer Science, which many LSE students complete.

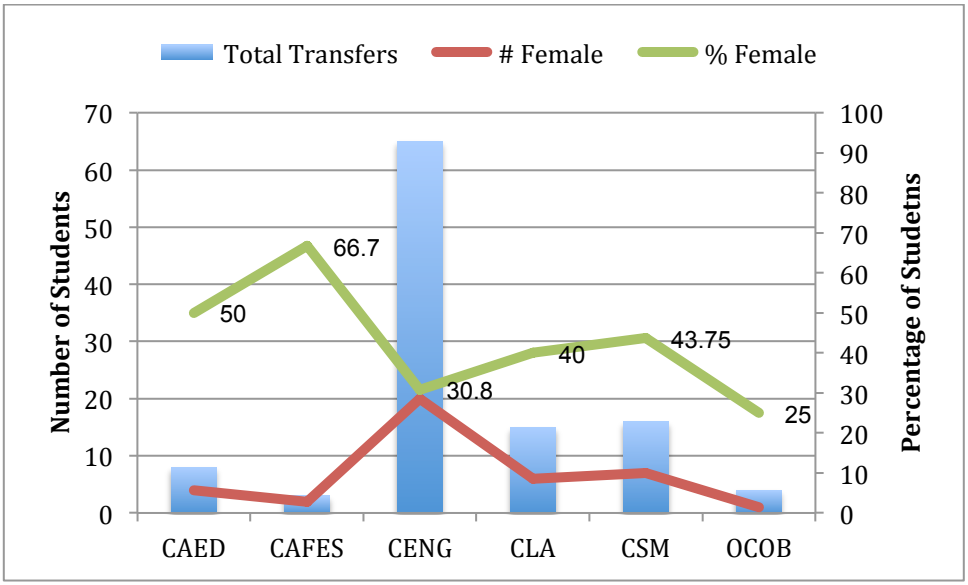

Figure 3: Transfer to LSE by College, Number Female, Percentage Female

Of the total 55 graduates from the program, eighteen graduated with an engineering concentration that included at least 4 quarters of the introductory computer science sequence (CSC 123, 101, 102, and 103) – and thus, for the purposes of this paper, function as a comparison group to the computing disciplines at CPSU and nationally. Of these eighteen LSE-computing disciplines alumni, seven, or 38.9%, are women. Of the current 55 students, 22 are "computing discipline" students, 22.7% (5) of which are female. Total to date, 30% of the LSE students with concentrations in the computing disciplines are female. What distinguishes LSE

from the other computing disciplines at CPSU is thus its higher rates of female recruitment, participation and success at the course and program level (see Figure 4).

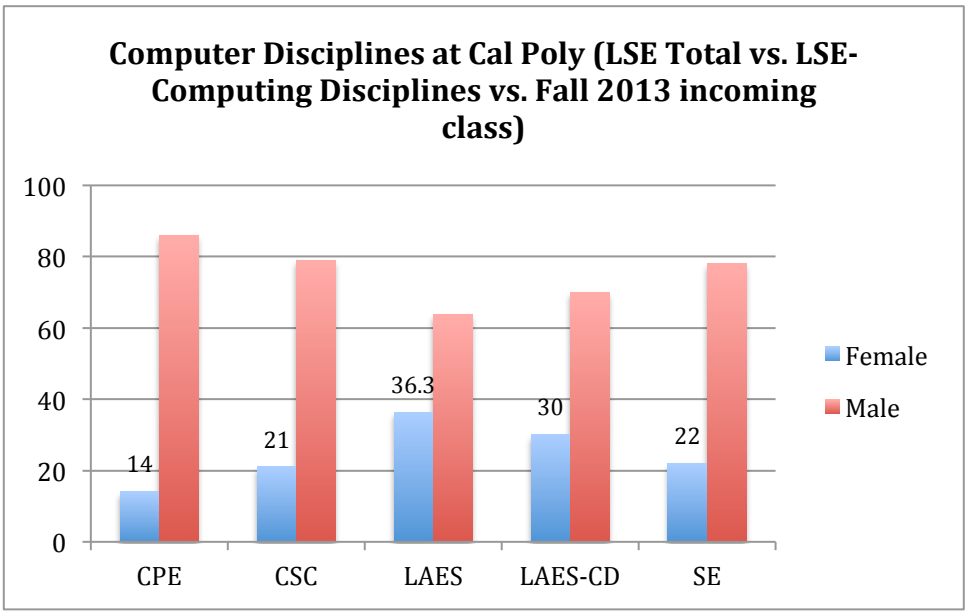

Figure 4: Computing Disciplines at CPSU (LSE total vs. LSE-Computing Disciplines vs. Fall 2013 incoming class)

The rest of this paper identifies and explores possible explanations for this difference as part of an effort to initiate a research agenda in this area.

Discussion: Why So Many More Women in LSE Compared to Other Computing Disciplines at CPSU? – Initiating a Research Agenda on B.A. Programs in Engineering Studies

One reason that we believe women students are both attracted to and more successful in LSE as compared to other computing disciplines at CPSU is the size of the major. LSE is a small major with a high level of group and one-on-one advising. To compare, within the broader College of Engineering, the typical college-level advisor to student ratio is 1:1200. For the LSE program, in contrast, we have one college-level advisor who is an expert in the LSE program plus other college-level advisors with emerging expertise; two LSE program faculty co-directors (one from the College of Engineering and one from the College of Liberal Arts); an additional faculty member functioning as an LSE transfer advisor and senior project co-advisor; one 80% administrative staff member – all of which lead to a comparatively high level of advising. In addition, in contrast to other majors within either the College of Engineering or the College of Liberal Arts, LSE students may apply for up to $1000 per year reimbursement for study abroad, senior project, and/or class projects. This means that the human and resource support available to each student in LSE are significantly different than those in other computing disciplines.

However, we also believe that the high degree of flexibility within the LSE major may also contribute. As part of the internal transfer process, LSE students complete an LSE "concentrations sheet" in which they plan their individualized curriculum for completion of the major. Students iteratively revise and recreate this individualize curriculum (and their broader

career plan) in a dialogue with faculty and staff advisors during their course of study – in some cases, students may revise their curriculum 5 or more times as part of this process. What is also distinct and important about this process is that the LSE program at CPSU explicitly understands these processes of revision and recreation as signs of success – in terms of growth of self-knowledge and increasing detail regarding post-baccalaureate plans – rather than as signs of failure of deviation. In all advising and academic interactions, students are thus encouraged to understand and design their major as a "whole-person technical degree" that does not require them to pass, to assimilate, to compartmentalize, or to conform to stereotypes.[15] This commitment is further symbolized and enacted via the combination of courses in engineering and the liberal arts as central to the major. We suggest that this holistic flexibility may disrupt barriers such as impostor syndrome[14] by positioning the student not as impostor but as designer and creator – even when enrolled in technical courses in which the sex/gender ratio is skewed male. In addition, the individualized nature of the LSE curriculum also allows students to, if they wish, to develop individualized socially relevant application/career paths as guiding features in their LSE curricula and project portfolio – even if their 34-unit engineering concentration is in one of the computing disciplines.

Our working hypothesis is that 1) the flexibility of the LSE curriculum, 2) the dual-centrality of engineering and liberal arts courses and projects, and 3) the potential to direct this curriculum by social relevance matter in the recruitment, retention, and graduation rates of female students in LSE. Other researchers and educators have previously suggested that underrepresentation can be addressed by re-evaluation of the "values and standards of science and science education"[16] and the development of a more gender-inclusive science and science education. Riley, et al (2009) call for the integration of "some classic themes of feminism [into engineering education and practice] — asking who benefits and who is harmed, critically examining assumptions and presumptions that create injustice, and creatively and energetically working for our dreams of what could be" to produce both more socially responsible engineering and, potentially, increase the recruitment and retention of female students.[17] Researchers at Worcester Polytechnic Institute have recently reported the results of a study in which female engineering graduates between 1974-2011 reported greater long-term impacts of project-based learning on their worldviews and personal and professional impacts than males in this cohort.[18] In their discussion section, authors Vaz, et al (2013) indicate that these results "are consistent with Busch-Vishniak and Jarosz's broad survey of the literature concluding that female students are more motivated by opportunities for social context and collaboration than males" (p. 15).[18, 19]

The ability to self-design an LSE curriculum towards social relevance resonates with more specific existing literature on the computer disciplines. For example, Margolis and Fisher (2002) identify significant differences in the reasons that female and male students choose to major in computer science, part of which include female students' emphasis on "computing with a purpose": 44% of women interviewed and 9% of men interviewed included making connections between computer science, other fields, and social context as part of what motivated their interest in the major.[10] More recently, Guzdial (2013), in a review of research over 10 years focused on efforts to teach introductory computer science courses with a media-focused context, found that the introduction of this Media Computation course improved retention within and beyond the course at multiple institutions – with more woman enrolling and succeeding in this context-based introduction to programming.[20] Qualitative analysis suggested that retention was linked to

students' experiences in the course as "a welcome opportunity to be creative," and as contextualized and relevant.[20]

Perhaps, indeed, an LSE degree offers the possibility of redefinition of what it means, looks, and feels like to be rigorous in technical education. As Riley (2013)[21] reminded us, as part of our efforts to increase participation in engineering and computing disciplines, we must ask:

- Who are we making engineering hard for?
- What is the purpose of our current conceptualization of rigor in engineering and engineering education?
- In what ways does it promote and limit access to our profession?
- How does the notion of rigor can reproduce inequality in upholding certain kinds of graduates as an implied standard in engineering?

However, further interview, focus group and survey-based research of our LSE students and LSE students at other universities is necessary to fully investigate this argument.

Our hope is that this paper functions as a springboard to this collaborative, cross-institutional research agenda as part of other nation-wide efforts to further develop and evaluate "liberal studies in engineering" programs. While significant amounts of published research have focused on the design and impact of blended "liberal studies in engineering" programs[22, 23, 24, 25, 26] (sometimes described as B.A. programs in Engineering Studies) similar to the program we describe at CPSU, surprisingly little of this research has attended to gender or the computing disciplines. We believe that it is time to integrate the diverse research focused a) the relationships between liberal education and B.S. programs in engineering and computer science, b) the integration of problem- and context-based education in B.S. programs in engineering and computer science, c) B.S. programs in engineering and computer science at liberal arts colleges, and d) the recruitment, retention, and success of women and other underrepresented groups in B.S. programs in engineering and computer science with e) specific attention to gender and other social factors in educational choices and trajectories in "liberal studies in engineering" B.A. programs.

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