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Sustainable Product Design: Designing for Diversity in Engineering Education*

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Current and future engineers will need to address sustainability's triple bottom line, simultaneously addressing financial, environmental, and social goals. There is also a need to improve diversity in engineering, both in the communities served by new technology and the representation of gender and ethnic minorities among engineering professionals. We present data gathered from 'Engineering 10: Introduction to Engineering Design and Analysis'. This freshman course includes a six-week Mechanical Engineering module entitled 'Sustainable Human-Centered Design', that covers both human-centered design techniques as well as the principles of sustainable design. We investigate these students' experiences, confidence, and goals, focusing on aspects that might vary with gender and ethnic affiliation. We suggest that enrollment diversity in engineering could be improved by teaching engineering in a manner that both complements the previous engineering and design background of all students, as well as emphasizes the learning goals most important to under-represented engineering students. We also recommend offering sustainability and service learning projects that appeal to women and ethnic minority students in order to pique their interest and encourage their pursuit of an engineering career.

Keywords: community-based design; project learning; freshman design; diversity in engineering; sustainable design

1. HUMAN-CENTERED SUSTAINABLE PRODUCT DESIGN

IN SPRING of 2008, the Department of Mechanical Engineering at the University of California, Berkeley launched a new course module around the theme 'Human-Centered Sustainable Product Design' in order to show that mechanical engineering research and practice had much to offer in solving the world's grand challenges in sustainability. An additional goal was to foster a welcoming environment for female and ethnic minority engineering students. Our premise was that introducing sustainability and community-service could be a means of attracting and retaining women and underrepresented minorities, and that the additional level of social benefit would be an added draw for all students. The intent was to 'change the conversation' about engineering in a way that publicly demonstrates the societal value of engineering, attracting a representative diversity of students to study engineering [1].

For this paper we define 'sustainability' as 'meet[ing] the needs of the present without compromising the ability of future generations to meet their own needs' [2]. Previous years' experiences in teaching sustainable design to teams attempting to meet the three-part goal of sustainability [3, 4] have built upon the framework presented in Fig. 1, based on the concept of sustainability as the intersection between the environment, the economy, and the social system [5]. This definition, not only emphasizes the environmental impact of products, but also includes economic viability and the social impact that engineering can have on society as a whole, as well as underserved communities.

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2. RELATED WORK

This paper builds on previous research on integrating sustainability, social values and engaging content into freshman engineering, design

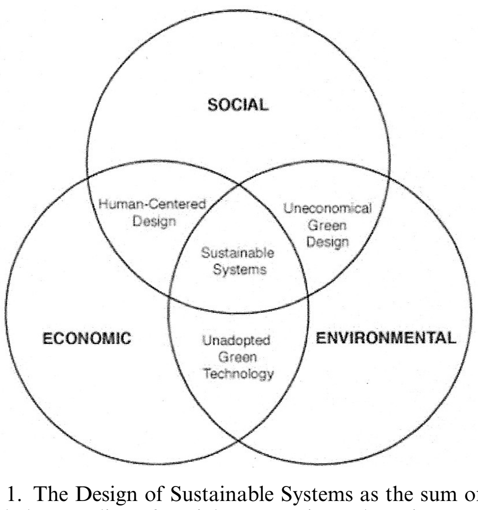

Fig. 1. The Design of Sustainable Systems as the sum of the triple bottom line of Social, Economic, and Environmental goals.

curricula and even analysis courses [6, 7, 8]. We contribute to this work by providing situational insight into students' previous engineering experiences, as well as qualitative and quantitative data concerning students' project theme preferences in an introductory engineering course at UC Berkeley.

Several other universities have also used sustainability as a theme in freshman design courses. However, these design courses often focus on detailed design or design specifications as opposed to needfinding and conceptual design. Lau [11] describes a freshman class at Penn State that uses a multi-interpretational approach to 'green design' that includes life cycle analysis (LCA), biomimicry, industrial ecology, and 'green design'. Kemppainen et al. [12] describe a freshman sustainable design course where first-year students were introduced to engineering through a sustainability-themed design project that focused on developing a green manufacturing process for a specific material (timber) in a specific region (upper peninsula of Michigan), as opposed to the design of a product that interfaces directly with an end user.

There is evidence that appropriate technology and sustainability-themed student-led design projects are disproportionately appealing to women. For example, Al-Khafaji and Morse [9] describes a student-led design course connected with the Stanford's chapter of Engineers for a Sustainable World. Zimmerman and Vanegas present a case study of Engineers Without Borders having an increase in the proportion of women in leadership roles [10].

3. TESTBED

In this paper, we present data gathered from 'Engineering 10: Introduction to Engineering Design and Analysis', for the Spring 2008 and Spring 2009 semesters at the University of California at Berkeley. E10 is an introductory engineering course designed to help entering freshmen transition into college and connect to engineering research and practice during their first year. The course is co-taught by faculty from different engineering departments in the College of Engineering. In Spring 2008, the departmental modules included those from Industrial Engineering and Operations Research (IEOR), Nuclear Engineering (NE), Civil and Environmental Engineering (CEE), and Mechanical Engineering (ME). Spring 2009 had the same offerings except there was no Nuclear Engineering module.

> **Course Description:** E10, *Engineering Design and Analysis*, is an introduction to the profession of engineering and its different disciplines through a variety of modular design and analysis projects. Hands-on creativity, teamwork, and effective communication are emphasized. Common lecture sessions address the essence of engineering design, the practice of engineering analysis, the societal context for engineering projects and the ethics of the engineering profession. Students choose two modules to develop design and analysis skills, and practice applying these skills to illustrative problems drawn from various engineering majors. [13]
>
> **Textbook:** Dym & Little [14].

The structure for the fifteen-week course was:

- A three-week introduction to the course and general themes that were to be addressed in each module.
- A six-week module in one of the engineering areas.
- A six-week module in a different engineering area.

The ME module was entitled 'Sustainable Human-Centered Design' and applied human-centered design techniques to sustainable design challenges. The other modules addressed engineering problems using a more technology-driven approach, but all modules shared the same learning goals with a focus on the general (a)–(k) ABET learning outcomes [15]. The ME module and the IEOR module were taught be female faculty and the NE and CEE module by male faculty.

This paper presents data gathered from two surveys in Spring 2008 and 2009: one data set of all E10 students, and another for only those students who participated in the ME module. In the survey of all E10 students, question topics included the students' previous experiences in engineering or design, including summer or after-school involvement in engineering-related programs or design competitions, and enrollment in high school courses in sewing, computers, shop, art, design, or drafting/CAD. We also asked the students to self-assess their abilities on engineering skills described by ABET program requirements [15].

- Analytical skills.
- Creativity and practical ingenuity.
- Develop designs that meet needs, constraints and objectives.
- Ability to identify, formulate, and solve engineering problems.
- Communication skills with multiple stakeholders.
- Team skills with people from diverse backgrounds and disciplines.
- Leadership and management skills.
- High ethical standard and a strong sense of professionalism.
- Dynamic/agile/resilient/flexible.
- Ability to learn and use the techniques and tools used in engineering practice.
- Ability to recognize the global, economic, environmental, and societal impact of engineering design and analysis.

Table 1. Number of students, including women and underrepresented engineering minorities, participating in E10 course, and specifically in the ME module

		2008			2009		
		Class	**Module 1**	**Module 2**	**Class**	**Module 1**	**Module 2**
Total Students		174	65	58	142	58	52
Gender	**Women**	45	17	12	34	13	12
	Men	129	48	46	108	45	40
Ethnicity	**African-American**	1	1	0	2	1	1
	Chicano	18	6	6	14	2	9

Table 1 lists the number of students, including women and under-represented minorities, participating in the full E10 course, as well as in the ME modules during semesters where the Sustainable Human-Centered Design module was offered.

In both years, the ME module proved to be the most popular module for all students. The most striking statistic, however, is that it was also the module with the highest percentage of women students (67% in 2008 and 73% in 2009), even though mechanical engineering nation-wide and at UC Berkeley has the lowest enrollment of women of all of the disciplines (UC Berkeley was close to the national average for universities in female engineering enrollment during these years: approximately 20% overall, 25–30% in Civil and Environmental Engineering, 25–30% in Industrial Engineering versus 10–13% in Mechanical Engineering [16]). Although too small in numbers to be statistically significant, it is interesting to note that all of the African American students chose to take the ME module (albeit there were only three altogether) and 67% and 79% of Chicano/ Latino/ Hispanic (hereafter referred to as 'Chicano') students took the ME module in 2008 (with four choices) and 2009 (with three choices), respectively.

We believe the disproportionate popularity among women supports our hypothesis that the content and the nature of projects matter in gendered choices about engineering. The disproportionate number of underrepresented minorities could also have been influenced by the fact that the ME module was unique in having an African American teaching assistant and a Chicano advisor to the Seguro project. All modules had a mix of male and female teaching assistants.

In the survey of students participating in the ME module, the students were given a wide range of sustainable design problems to choose, including those that addressed the needs of underserved communities, such as migrant farm workers in Central California and a Native American community. To form teams, the students were asked to rank their top three project choices and were typically assigned their first or second choice. The proposed projects are provided in Table 2. Because complete project preference data were not available for the Spring 2008 Module 1, it is not included in the analysis that follows.

The Seguro Materials Testing project addressed pesticide protection of the migrant farm worker community, and all the Pinoleville Pomo Nation (PPN) projects focused on the energy and culturally sensitive housing needs of this Northern California Native American community. All other projects focused on the more 'mainstream' users catered to by engineering designers, including college students.

In the rest of the paper, we review significant results by gender, which distinguish self-perception of skills and self-selection of projects for the female students relative to that of their male counterparts in Spring 2008 and Spring 2009.

It should be noted that due to the limited number of African-American students (3) and Chicano students (32) enrolled in E10 for Spring 2008 and 2009, we were only able to find significant differences between underrepresented ethnic minority and non-minority populations in a few cases. However, these few students still provided valuable anecdotal information about their experiences in the ME design modules.

Table 2. Project options from 2008 Module 2, and 2009 Modules 1 and 2

2008 Module 2	**2009 Module 1**	**2009 Module 2**
• Smart Lighting • Seguro Materials Testing for Pesticide Protection • Pinoleville Pomo Nation (PPN) Sustainable Building • Dorm Room Furniture • Bicycle Transportation • Humanizing Hesse Hall • Composting at Cal	• Smart Lighting • Seguro Materials Testing for Pesticide Protection • PPN Solar Thermal Energy • PPN Renewable Electricity • Greening Your Dorm • Black Cloud—Art and Technology for Sustainability • Mobile Learning	• Smart Lighting • Seguro Materials Testing for Pesticide Protection • Pinoleville Pomo Nation (PPN) Sustainable Building • Greening Your Dorm • Black Cloud—Art and Technology for Sustainability • Mobile Learning • Wind Energy in Golden Gate Park

4. ENGINEERING EXPERIENCE

In the course entrance survey, we asked all students to mark whether or not they had participated in a variety of engineering-related experiences in high school. These experiences are shown by gender in Fig. 2 and by ethnicity in Fig. 3. To test significance, a chi-squared test was used with a critical value of $p < 0.05$.

Based on data from Spring 2008 and Spring 2009, we found that a significant number of women in E10 had participated in design competitions in high school, in comparison to men ($p = 0.028$). This could be an indicator that these design competitions are succeeding in encouraging women to pursue engineering; hopefully this showing that targeted outreach works.

It is not surprising that male students were more likely to have taken a shop course ($p = 0.01$), indicating that providing women hands-on shop experience in a female-friendly environment might boost their confidence level to that of their male counterparts. This is one reason that the ME module contained a substantial hands-on design and prototyping component. It is interesting to note that none of the men and very few of the women had taken a sewing course. The gender differences, however, were not statistically significant, probably due to the low number of students taking sewing as a class in high school.

The Chicano students' backgrounds before arriving at engineering (Fig. 3) had significantly more shop classes ($p = 0.009$) and showed a trend to more art classes ($p = 0.096$). This indicates that engineering interest could be sparked by other creative, hands-on courses in addition to the traditional math-and-science pathway to engineering for this group.

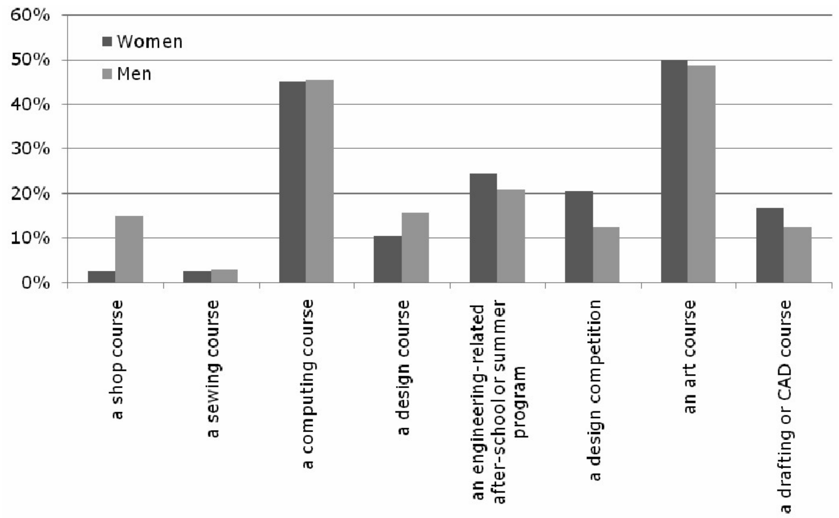

Fig. 2. Percent of students who had high-school engineering experience, by gender, combining results from both Spring 2008 and Spring 2009. Men were more likely have participated in shop courses in comparison to women ($p = 0.01$). Women were more likely than men to have participated in design competitions ($p = 0.028$). (Statistical analysis was performed with a Chi-squared test.)

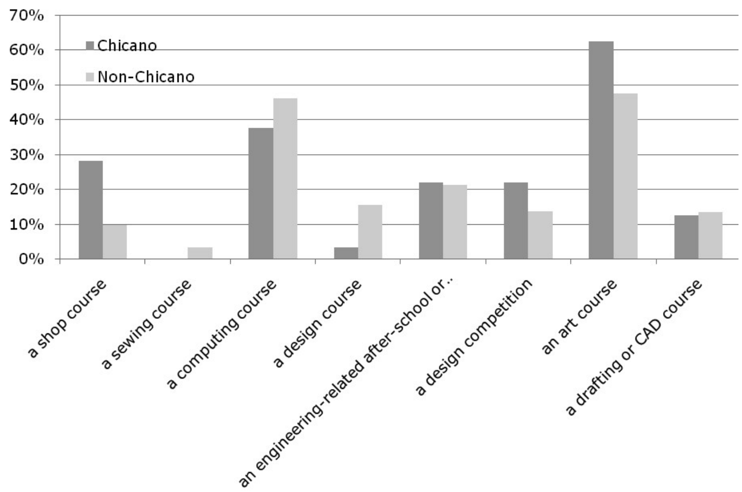

Fig. 3. Percent of students who had high school engineering experience, by ethnicity, combining results from both Spring 2008 and Spring 2009. A significantly higher percentage of Chicanos had participated in shop courses in high school, in comparison to the non-Chicanos ($p = 0.009$). There was a trend for Chicanos to be more likely to have taken an art class ($p = 0.096$). (Statistical analysis was performed with a Chi-squared test.)

Table 3. ME Module course ABET Engineering Skills Confidence Values, for all students. Statistically significant results shown in **bold (including borderline cases)**

ABET Eng. Skills	Avg. Confidence Before	After	p
Analytical Skills	4.116	4.15	0.815
Creativity and Practical Inquiry	3.983	4.083	0.477
Develop designs that meet needs, constraints and objectives	**3.75**	**4.066**	**0.0315**
Ability to identify, formulate, and solve engineering problems	**3.683**	**4.133**	**0.003**
Communication skills with multiple stakeholders	3.483	3.65	0.347
Team skills with people from diverse backgrounds and disciplines	**3.766**	**4.083**	**0.058**
Leadership and management skills	3.666	3.9	0.181
High Ethical standard and a strong sense of professionalism	4.05	4.183	0.437
Dynamic/agile/resilient/flexible	3.983	3.983	1
Ability to learn and use the techniques and tools of engineering practice	4.116	4.1	0.913
Ability to recognize the global, economic, environmental, and societal impact of engineering design and analysis	**3.616**	**4.033**	**0.022**

5. ABET ENGINEERING SKILL CONFIDENCE INITIAL SELF ASSESSMENT

As part of the survey at the beginning of the E10 course, we asked the students to self-assess themselves (using a 5-option Likert scale) on a variety of engineering skills, based on the ABET requirements [15]. The results by gender are shown in Fig. 4. To test significance, a two-tailed Student's *t*-test was used with a critical value of $p < 0.05$.

The students' self-assessment followed gender trends where the men self-rated their analytical skills over the women's self-assessment ($p = 0.001$). Men also rated their ability in engineering problem solving ($p = 0.015$) and use of the tools of engineering practice higher as well ($p < 0.001$). The women, on the other hand, self-rated their skills higher in communication, teamwork, leadership and ethics ($p = 0.014$, $p < 0.001$, $p < 0.045$, $p < 0.001$, respectively). The women also rated themselves higher in 2008 ($p = 0.054$) for their ability 'to recognize the global, economic, environmental, and societal impact'. The gender difference in this last skill was displayed in 2009 as well, but was not statistically significant. This pattern is consistent with previous studies that have demonstrated women's lack of confidence in their analytical math and science skills [17] and possible gender differences in value priorities [18]. These results add the potential for using women's higher confidence in 'people skills' and sensitivity to social impact to attract more women into engineering as they are key skills for success in engineering practice [15].

Chicanos were the only underrepresented ethnic

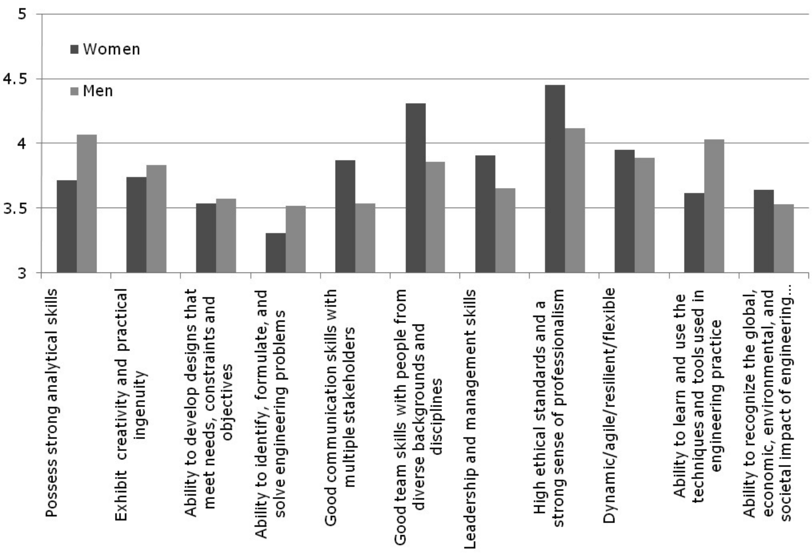

Fig. 4. Skill Confidence at the start of the class by Gender, combining results from both Spring 2008 and Spring 2009. The men's self-assessment rating was significantly higher than the women's self-assessment rating for analytical skills ($p = 0.001$), engineering problem-solving ($p = 0.015$), and their ability to use the tools of engineering practice ($p < 0.001$). The women's self assessment rating was significantly higher than the men's self-assessment rating for communication skills ($p = 0.014$), teamwork skills ($p < 0.001$), leadership and management skills ($p = 0.045$), and ethics ($p = 0.001$). (Statistical analysis was performed with a two-tailed Student's t-test with a critical value of $p < 0.05$.)

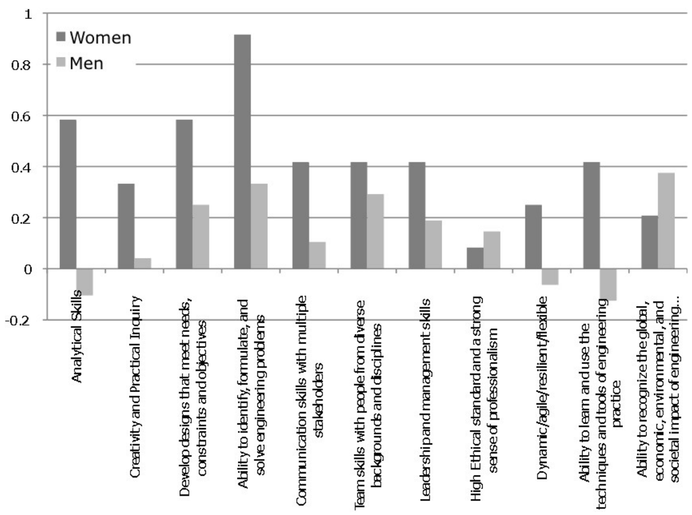

Fig. 5. Improvement in Average Skill Confidence after taking the ME module, by Gender for Spring 2009. While both men and women were more confident in their ability to identify, formulate, and solve engineering problems ($p = 0.003$ as a group), the women's confidence had improved significantly ($p = 0.005$) more than the men's (improvement of 0.916 points for women versus 0.333 for men). Women also showed a statistically significant improvement in their confidence of their analytical skills ($p = 0.026$) and borderline significant improvement in design skills ($p = 0.055$ for women and $p = 0.0315$ for men and women combined). Both men and women showed a trend for improved recognition of global impact ($p = 0.022$ combined, $p = 0.055$ for women and $p = 0.08$ for men) after participating in the module's sustainable design projects. Note: there was no change in the men's confidence in analytical skills (Statistical analysis was performed with a paired two-tailed Student's t-test was used with a critical value of $p < 0.05$.).

minority in large enough numbers for analyses by ethnic group. The only skill with a statistically interesting difference in this population was in the 'team skills with people from diverse backgrounds.' They rated themselves at 4.25 on average using a 5-point scale, whereas the majority students were at 3.94 ($p = 0.07$).

6. ABET ENGINEERING SKILL CONFIDENCE: BEFORE AND AFTER ME MODULE

At the end of the first Mechanical Engineering Module in Spring 2009, the students in the module were asked to rate their confidence in skills again. To test significance, a paired two-tailed Student's t-test was used with a critical value of $p < 0.05$ (Fig. 5). The overall improvement for that class was statistically significant in the students' confidence in their ability to develop designs that meet needs, constraints and objectives ($p = 0.0315$), solve engineering problems ($p = 0.003$), and to recognize the global and environmental impact of engineering and design ($p = 0.022$). Improved confidence in team skills were on the borderline of significance ($p = 0.058$).

Tables 4 and 5 show, respectively, how men's and women's confidence levels in engineering skills changed from before to after taking the ME module. The women's confidence in engineering problem solving improved significantly ($p = 0.005$) more than the men's (improvement of 0.916 points for women versus 0.333 for men). Women also showed a statistically significant improvement in confidence in their analytical skills ($p = 0.026$).

Table 4. ME Module course ABET Engineering Skills Confidence Values, for all male students. Statistically significant results shown in **bold (including borderline cases)**

	Avg. Confidence (Men)		
ABET Eng. Skills	**Before**	**After**	***p***
Analytical Skills	4.271	4.167	0.518
Creativity and Practical Inquiry	4.042	4.083	0.791
Develop designs that meet needs, constraints and objectives	3.771	4.021	0.139
Ability to identify, formulate, and solve engineering problems	**3.750**	**4.083**	**0.059**
Communication skills with multiple stakeholders	3.458	3.563	0.594
Team skills with people from diverse backgrounds and disciplines	3.750	4.042	0.118
Leadership and management skills	3.625	3.813	0.335
High Ethical standard and a strong sense of professionalism	3.958	4.104	0.468
Dynamic/agile/resilient/flexible	3.938	3.875	0.720
Ability to learn and use the techniques and tools of engineering practice	4.146	4.021	0.476
Ability to recognize the global, economic, environmental, and societal impact of engineering design and analysis	3.583	3.958	0.080

Table 5. ME Module course ABET Engineering Skills Confidence Values, for all female students. Statistically significant results shown in **bold (including borderline cases)**

ABET Eng. Skills	Avg. Confidence (Women) Before	After	p
Analytical Skills	**3.500**	**4.083**	**0.026**
Creativity and Practical Inquiry	3.750	4.083	0.303
Develop designs that meet needs, constraints and objectives	**3.667**	**4.250**	**0.055**
Ability to identify, formulate, and solve engineering problems	**3.417**	**4.333**	**0.005**
Communication skills with multiple stakeholders	3.583	4.000	0.328
Team skills with people from diverse backgrounds and disciplines	3.833	4.250	0.295
Leadership and management skills	3.833	4.250	0.295
High Ethical standard and a strong sense of professionalism	4.417	4.500	0.764
Dynamic/agile/resilient/flexible	4.167	4.417	0.275
Ability to learn and use the techniques and tools of engineering practice	4.000	4.417	0.196
Ability to recognize the global, economic, environmental, and societal impact of engineering design and analysis	**3.750**	**3.958**	**0.055**

There was no statistically significant change in the men's confidence in their ABET skills as a group separate from the total population.

7. GENDER AND PROJECT PREFERENCES

At the beginning of each ME module, we asked the students to rank their top three project preferences. The selection of projects varied from year to year, and was adjusted between modules. Table 6 shows the percentage of men and percentage of women who included a given project in their top three preferences. Differences in the project preference rankings were tested for significance using the Mann-Whitney U-test. This test considers all top three rankings, and weights each project based on the number of students who ranked the project first, second, and third.

The only statistically significant result is that women showed a gender preference for the Mobile Learning project during the second rotation of Spring 2009 (75% for women and 45% for men, $p = 0.013$) and a trend in the first rotation (62% women versus 44% men, $p = 0.135$). The project was not offered as a choice in 2008. We speculate that this could be due to women's interest in education issues, as evidenced by the high percentage of women in education as a discipline and profession. There also appeared to be a trend for men to prefer the Bicycle Transportation project, which was only offered in 2008 (41% for men,

Table 6. Percent of Women/Men who ranked a project in their top three choices. Significance values are in the far right column. Statistically significant results are in **bold**; statistically interesting results are *italicized*

2008 ME Module 2	% Women	% Men	p
Smart Lighting	50.0	56.5	0.561
Bicycle Transportation	*8.3*	*41.3*	*0.141*
Portable Electronic Devices	33.3	50.0	0.368
Dorm Room Furniture	58.3	54.3	0.319
Hesse Hall	25.0	30.4	0.538
Seguro Materials Testing	*58.3*	*30.4*	*0.134*
Composting at Cal	25.0	13.0	0.292
Pinoleville Pomo Nation Buildings	*41.7*	*23.9*	*0.134*
2009 ME Module 1	**% Women**	**% Men**	**p**
Smart Lighting	53.85	62.22	0.518
Black Cloud	38.46	20.00	0.175
PPN Solar Thermal Energy	30.77	46.67	0.739
PPN Renewable Electricity	30.77	44.44	0.451
Mobile Learning	*61.54*	*44.44*	*0.135*
Greening Your Dorm	38.46	35.56	0.397
Seguro Materials Testing	46.15	44.44	0.721
2009 ME Module 2	**% Women**	**% Men**	**p**
Smart Lighting	41.7	60.0	0.517
Greening Your Dorm	25.0	25.0	0.598
Wind Energy in Golden Gate Park	*41.7*	*67.5*	*0.081*
PPN Sustainable Building Design	25.0	37.5	0.414
Black Cloud	33.3	30.0	0.543
Seguro Materials Testing	*58.3*	*35.0*	*0.131*
Mobile Learning	**75.0**	**45.0**	**0.013**

versus 8% for women, $p = 0.141$), and the wind energy project, which was only offered in 2009 Module 2 (68% for men, versus 42% for women, $p = 0.081$).

As a trend, women were more interested than men in the Seguro project for pesticide protection of migrant farm workers in the second module of Spring 2008 (58.3% women versus 30.4% men, $p = 0.134$) and the second module of Spring 2009 (58% women versus 35% men, $p = 0.131$). Women also had a trend to be more interested in the Pinoleville Pomo Nation (Native American community) project in 2008 (42% women versus 24% men, $p = 0.134$), but not in 2009. We believe this may be due to the framing of the problem in 2009 as one that focused on energy calculations and less on community–centered design.

8. QUALITATIVE COMMENTS

A qualitative analysis of student's comments provides insights into some of the choices made. For example, although there were no statistically striking differences in project selection by ethnicity, one comment by a Chicano student, whose first choice was the Seguro Materials Testing project, indicated that personal relevancy was a major reason for the project choices:

> I chose the material testing because I know people who would actually be affected by these suits. It would be a great opportunity to aid them in anyway. I chose the mood lighting second because my room already has lights that are specifically just to set a tone, and not for any other purpose. The last choice is because renewable energy is important for our future and it could be interesting to see how wind turbines work.

One female student, whose first choice was the PPN project, provided this reason for her project choice:

> I liked the Pomo Nation project the best because I thought it would be really interesting to design an entirely green building; there are so many options it would be fun to come up with the best options that would best fit the needs of the nation. [. . .] I also liked the Seguro Materials Testing Materials Testing a lot because it seemed very hands on and I like that. When I work on a project I like to be physically and mentally engaged. It helps me be more creative. I really do not want to work on a project that is going to be mostly theoretical because I do not find that interesting or engaging.

Five of the twelve female students in the second module of 2009 brought up environmental themes (care about the environment, interest in renewable/alternative energy, etc.) as their rationale for selecting their project.

A female student from one of the PPN teams stated:

> I absolutely loved this class and I wish that both modules had been structured like the ME Module. I enjoyed learning and practicing the design process. I absolutely loved being able to be creative and feeling that I could make a difference in the world around me.

Another female student from one of the PPN teams stated:

> The class was very useful in getting students' creative natures to come out. It showed how design is a very important part of engineering. I like the whole design project.

This student found the Mechanical Engineering module as a bridge between design and engineering, as a link back to the students' 'creative natures'.

One female student from the second module in 2008, who participated in the PPN project, has continued to work with the project and is now switching her major from Civil Engineering to Mechanical Engineering based on her experiences.

It was reassuring to see positive comments by majority students as well. One male, Asian-American student wrote in his design journal:

> Today was essentially the kick-off for our human-centered sustainable design project. To be hones, I'm rather excited about it. I was assigned to my first choice project—solar electricity generation for the Pinoleville Pomo Indian tribe. I've been interested in alternate forms of energy for a long time, and am eager to learn more about, not to mention have the chance to work on my first genuine engineering project.
>
> Today, we had our innovation workshop at the PPN reservation in Ukiah. Man-where to begin! Overall, I'd have to say the experience was a positive one. I mean yes, it was a bit of a hassle getting there and it was certainly a very long day, but I feel that the knowledge gained about the PPN people and their needs . . . It was a productive/ informative day, and I look forward to beginning the design process with my team mates.

Although the teaching evaluations were high and most comments were positive, this variant of 'the exception that proves the rule' example indicates that one majority male student in 2008 felt the course was not reaching him.

> I hated this module. From my understanding of E10, it should communicate to people what the different types of Engineering are about. To me, it failed abysmally at doing that. It communicated what Human Centered Design is, but that is not what all of Mechanical Engineering is. I would actually be turned away from Mechanical Engineering if this module was my first introduction to it and I hadn't competed in over 20 robotics seasons and had years of experience in outside of High School that taught me what Mechanical Engineering can be.

This highly accomplished student did not connect human-centered design with mechanical engineering. He views the discipline as one that can be defined as building robots to compete. The comment does raise the question about how we are communicating engineering to K-12 students. Whereas the dueling robots can be engaging to many students, we should do a better job of communicating the societal impact and benefits of engineering as well.

Perhaps by neglecting to emphasize the human side of engineering, where societal and ethical problems frame and motivate the engineering practice, we're also forgetting to emphasize the part of engineering that appeals most to underrepresented minorities in engineering (women and some ethnic minorities). We did bring this student in to help us redesign the modules for the 2009; although we want to attract diverse students, we do want to have options that appeal to traditional engineering students as well.

9. CONCLUSIONS

In this study, we found that female students come into our engineering program at UC Berkeley with different levels of confidence in their ABET-related general engineering skills. Men had higher levels of confidence in their analytical skills, engineering problem solving skills and their ability to use engineering tools. Women, on the other hand, had higher confidence in their communication skills, teamwork skills, leadership and management skills, and ethics. These results suggest that recruiting women into engineering by stressing mathematical ability and software skills may not be as effective as stressing the importance of the professionals skills associated with effective teams. This finding is consistent with that of the National Academy of Engineering's marketing study—'Changing the Conversation Messages for Improving Public Understanding of Engineering' [1].

Although all students showed general improvement in most of the ABET-related engineering skills after taking our introductory engineering module, women showed striking benefits in confidence building in regards to analytical, engineering problem solving, and design skills.

The statistical trends of project preferences and the qualitative analysis of students' rationale for their project choices indicate that women and minorities may also be attracted to projects that clearly show a societal benefit. Our hypothesis is that we can potentially improve recruitment and retention of underrepresented engineering students by better integrating service learning, sustainability, and issues in underserved communities. We are currently performing a longitudinal study by gender and ethnicity of our recruiting and retention practices.

Diversity has many dimensions beyond race and gender, however. Through our choice of engineering projects and our human-centered design approach, we hope to engender a diversity in ways of thinking about engineering and its potential positive impact on society. Our Human-Centered Sustainable Design module showed a statistically significant improvement in sensitizing all students to 'recognize the global, economic, environmental and societal impact of engineering design and analysis'.

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