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Complex Systems: Interactions Between Gender and Project Context on Confidence of First-Year Engineering Students*

LAURA J. HIRSHFIELD
Chemical Engineering, University of Michigan, 2300 Hayward St, Ann Arbor MI, 48104, USA. E-mail: lhirshfi@umich.edu

DEBBIE CHACHRA
Olin College of Engineering, 1000 Olin Way, Needham MA, 02492, USA. E-mail: debbie.chachra@olin.edu

In first-year team-based engineering projects, students have the opportunity to become familiar with the field, gain knowledge and skills, and develop engineering self-confidence and self-efficacy. How engineering students gain (or lose) this confidence depends in part on the opportunities that they have to complete mastery experiences, in which they successfully complete tasks that allow them to feel more capable as engineers. However, all students may not be engaging similarly in mastery experiences, and thus, they may not experience the same benefits from the project experience. In this study, we focused on students enrolled in first-year engineering project courses at two different institutions, to investigate the differences that exist between the mastery experiences that they complete, their changes in engineering confidence and self-efficacy, how these two factors interact, and how these aspects are different depending on the student's gender identity. We found that although men started the semester with generally higher confidence and self-efficacy than women, this gap closed by the end of the course. In investigating the relationships between these changes in confidence and self-efficacy and the time devoted to different tasks, it was found that the engineering confidence of students generally benefited more from spending time on non-gender-stereotypical tasks; although it may seem counter-intuitive, spending more time on technical tasks is linked to a *decrease* in confidence for women. Finally, there were marked differences between the women at each institution in how they spent their time or experienced changes in engineering confidence and self-efficacy. These results suggest that task choice and self-efficacy are sensitive to the learning experience in a way that *interacts* with student demographics, rather than student demographics being the dominant contributor to their experience in a project course; that is, while gender is a factor, the specific effects depend on the academic context.

Keywords: First-year engineering; project-based learning; self-efficacy; confidence

1. Introduction

The practice of engineering is a complex endeavor that requires a host of integrated skills and knowledge, including technical content, design, analysis, and communication. Very little engineering is carried out in isolation: almost all professional practice is carried out in small or large teams, whether focused on one field or interdisciplinary. Similarly, much of engineering work is project-focused. Accordingly, there has been a widespread move to build teaming and project experiences into the undergraduate engineering curriculum, scaffolding the development of these skills while also attempting to increase student interest, motivation and retention [1].

However, these new pedagogical experiences do not exist in a vacuum. While the percentage of women in engineering has increased over time [2], engineering as an academic discipline remains dominated by men at the student and at the faculty level, not just numerically but also culturally. In other words, schemas that men are better suited to be engineers than women are manifested in the professional socialization of new entrants to the field (i.e. undergraduate students) [3–5]. As well as these engineering-specific issues, a host of gendered behaviors involving leadership and communication are in play during interpersonal interactions. That suggests that learning experiences that lean heavily on collaborations with peers – like teaming experiences and project-based learning – will almost certainly reify these existing norms and differences. Similarly, stereotypes about "male" tasks (non-personal, technical, traditional engineering tasks) and "female" tasks (personal, social, non-technical tasks) can contribute to gender differences in the learning experiences for students [6]. And indeed, that's precisely what has been observed. It has been found that, in first-year engineering project teams, men are more likely than woman to take on technical roles and to talk more, and about more technical topics [7]. Men are more likely to emerge as leaders and are perceived to be more knowledgeable than their female peers [8]. What these findings suggest is the need for a continued effort to understand how students engage in and respond to teaming and project experiences in order to create learning experiences that support students in achieving the desired academic outcomes without

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running afoul of gender norms; educators need to create an environment that does not differentially benefit some engineering students at the expense of others.

In addition to the academic outcomes and the development of engineering skills, the types of experiences that students have in these hands-on, team-based project courses also affects their engineering self-efficacy: their self-perceived capability to engage in hands-on engineering tasks and be successful [9]. Self-efficacy is key to persistence and retention in undergraduate engineering education, particularly for women, who often leave engineering not because of low grades or other external evidence that they are not capable, but because of low self-confidence or self-efficacy [10]. One of the main contributors to self-efficacy is "mastery experiences," in which students succeed at completing activities that make them feel more capable. Thus, if women predominantly shoulder "helper" or administrative roles in their team projects, and miss out on technical roles, they may not have the same mastery experiences in engineering as their male colleagues. Although stereotypically female tasks (scheduling, writing, communicating) are important to engineering, experiences of technical engineering tasks (design, hands-on work, modeling) are necessary for women to have the opportunity to develop skills and have the opportunity to increase their engineering self-efficacy. Accordingly, for this study, we investigated student involvement in engineering mastery experiences in hands-on, team-based engineering design courses in two different academic contexts. We looked at students' academic self-confidence and engineering self-efficacy at the start of the course and how the mastery experiences that they took on over the course of the project may have affected their academic and engineering confidence and self-efficacy at the end of the course. The results presented are drawn from a larger study [11]; here, findings are viewed and analyzed here through the specific lens of comparing the experiences of men and women.

2. Background

2.1 Women in Undergraduate Engineering Programs

It is widely acknowledged that women in undergraduate engineering education have different experiences than their male peers. This is not just because women are in the minority, but also because of the framing of the tasks inherent to engineering work and the academic or professional environment: engineering is stereotypically considered to consist of technical, non-personal tasks which are inherently "male," as opposed to non-technical, social tasks that are inherently "female" [6, 7]. Engineering culture also can be biased towards men, in that behaviors that are men are more comfortable with (i.e. swearing, violent metaphors, sexual jokes) may be prevalent, and women may be uncomfortable but feel unable to redefine the accepted behaviors [4]. In projects and internships, women report that they are being relegated to helper or supporting roles, that their coworkers assume that they lack expertise, and that they are not offered the same technical opportunities as their male colleagues [3].

This male-coded climate likely has a direct negative impact on recruitment and retention of women in engineering. After steadily increasing from the 1970s, the percentage of women receiving undergraduate degrees in engineering has been holding steady at approximately 20% for the last 15 or so years [2]. Women commonly drop out of engineering after the sophomore year, citing various reasons for leaving: loss of interest, dislike of teaching styles, experiencing conceptual difficulties, feeling their rewards are not worth the effort, or receiving low grades [12]. The percentage of women in the engineering workforce is even lower than those who receive engineering degrees [13], and this is similarly attributed to an environment in which women feel like they don't have the same opportunities for professional growth and success as their male counterparts [3].

2.2 Gendered Experiences in Project-Based Learning in Engineering

It is against this backdrop of gendered socialization in engineering that we review project-based learning, which has become a key part of many engineering curricula. Projects generally require students to work in groups to employ technical and non-technical skills and apply knowledge to solve a complex, open-ended problem [14, 15]. Project-based learning may particularly appeal to female students, as they are more likely to be learner-centered, interdisciplinary, and focused on a social context [16], and there is some evidence that project-based learning increases retention of female students in engineering [17–21].

However, there is also evidence that project-based learning in the first year of an engineering curriculum had a greater impact on the retention of men and of other students who were not classified as underrepresented minorities [22]. While projects may be appealing to female engineering students, the math, science and technical aspects of engineering projects can still be considered to be stereotypically "male" tasks [6]. Women who are aware of these stereotypes may consciously or subconsciously be less motivated to participate in challenging technical tasks [23, 24]. Compared to men, women have been found to do fewer hands-on technical tasks in team projects [25, 26], to take on less-technical roles (like organizer or notetaker) [3, 7] and, in final oral presentations, talk less, answer fewer questions, and present less technical content [8]. This may not only be because women are less inclined to take on technical tasks; it may be because women are being assigned these tasks by their peers, or because they feel compelled to take on less-desirable tasks that no other student claims as their own. Thus, although project-based learning may appeal to female students broadly, they may not be engaging in similar activities as their male counterparts.

2.3 Development of Engineering Self-Efficacy in Project-Based Learning

Beyond inhibiting development of their skills, if women have less challenging, technical experiences, they are less likely to develop confidence or engineering self-efficacy, which can have damaging effects on retention of women in engineering. In fact, the primary reason that women drop out of engineering is low academic self-confidence [10, 27]. Academic self-confidence has been found to be related to many aspects of the college experience; confidence in math and science, specifically, has been found to be significantly related to student persistence in engineering [28, 29]. Self-efficacy, the strength of one's belief in one's ability to succeed [9], is also a factor in student persistence and identity [30–33]. While academic self-confidence applies across broad domains, self-efficacy is more narrowly focused, and has to do specifically with perceptions of capabilities. Beyond retention, self-efficacy influences many aspects of students' motivation: the choices and decisions that they make, their perceptions of challenges, the amount of effort they are willing to make to overcome adversity or complete a task [34–36]. Perhaps the most relevant aspect of self-efficacy in the context of undergraduate engineering programs is that "individuals with strong self-efficacy beliefs work harder and persist longer when they encounter difficulties than those who doubt their capabilities" [37, p218]. While women and men may start their engineering programs with similar levels of self-efficacy [38], women can lose confidence over time [39, 40].

The development of self-efficacy can be affected by external factors (social persuasion, vicarious experiences) or internal factors (physiological states). The fourth factor in the development of self-efficacy, and the factor most relevant to project-based learning experiences, is *mastery experiences.* Projects, especially hands-on projects, are generally intended to provide students with the opportunity to complete mastery experiences: tasks which make students feel more prepared to be an engineer. Mastery experiences are only beneficial to students if they have the opportunity to succeed; if students feel they have failed or do not have the opportunity to approach the task at all, the experience may instead negatively impact their self-efficacy. In general, mastery experiences are considered to be the contributor with the strongest influence over self-efficacy [9, 31, 37, 41, 42] and thus it is often assumed that if students are provided with the chance to complete valuable engineering activities, then their engineering self-efficacy will increase commensurately. However, as discussed previously, women engage in different activities in projects than their male counterparts, and thus are having different mastery experiences. Furthermore, women who are already entering the field with lower confidence or self-efficacy than their male counterparts [39] may not take on challenging technical tasks or tasks that are new to them, because they are less confident, more self-critical, and may wish to avoid new situations or disappointing their team [43]. This is consistent with findings that, in a hands-on, team-based project experience, female students experienced a smaller (or no) increase in engineering self-efficacy compared to male students [44].

Against this male-coded engineering culture and with a knowledge of the development of self-efficacy, it is important to investigate female students' project-based learning experiences and how these experiences contribute to their self-efficacy. As women may have lower academic self-confidence entering into a project course, and because of the gendered nature of engineering work and culture, women may be less likely to take on engineering tasks during the project, resulting in the smaller increase (or no increase, or even a decrease) in academic self-confidence or engineering self-efficacy that has been observed for women in project courses compared to their male counterparts. The research questions devised for this study investigate each element of this hypothetical mechanism, focusing on first-year, team-based project-based learning engineering courses which incorporate a hands-on engineering design component.

2.4 Research Questions

In order to study how project experiences in hands-on engineering design courses affect the engineering confidence or self-efficacy of male and female students, we articulated five research questions.

The first two questions relate to how engineering confidence and self-efficacy change throughout the project course in two different academic contexts:

1. How do engineering confidence and self-efficacy compare between the men and women in each of two different institutions?
2. How do engineering confidence and self-efficacy change for men and women over the course of the semester in which they are enrolled in a project course?

Next, we consider the specific activities that students do as part of their team projects, as a way to investigate the mastery experiences that students are completing in projects.

3. How are men and women spending their time differently in team projects?

We then consider the relationships between the students' confidence level and the tasks and roles that they take on.

4. How does students' incoming confidence or self-efficacy level influence the tasks that they take on?
5. Which tasks lead to changes in engineering confidence or self-efficacy?

3. Methods

3.1 Participants and Setting

This study focuses on first-year students enrolled in first-year hands-on design project courses, over three academic years, from 2012–2015. Students were enrolled at two different academic settings in the United States: a small private engineering college (SPrC) located in the northeast, and a large public university (LPU) located in the Midwest. Datasets within each institutional setting and across each academic year were pooled after determining there was no significant difference in demographics or reported confidence or self-efficacy measures between each academic year cohort, and because the courses were largely unchanged between successive years. However, there were significant differences between the engineering confidence and self-efficacy measures at the SPrC and at the LPU, so the two datasets were analyzed and compared individually. This resulted in one dataset for the SPrC and one dataset for the LPU. Furthermore, while both academic institutions are selective and well-regarded, they are notably different: one is a small, private residential engineering college which emphasizes team-based and hands-on work, and the other is a large, public university with comprehensive offerings, and which offers a more traditional engineering curriculum. These two schools were likely to have both drawn from different student pools and attracted different student populations; there is no *a priori* reason to presume that the students were similar, and this was borne out in the observed statistical difference. In addition to these structural differences, the small private college is demographically distinct from the large university (and most engineering programs), in that the student body is 50% female. Finally, the projects at each of these two academic contexts were also structured and scaffolded differently; these different learning experiences might also be expected to have differing impacts on changes in engineering confidence and self-efficacy, in different ways.

At both institutions, students were participating in a first-year multidisciplinary engineering design project course. At the SPrC, the first half of the course consisted of an individual hands-on project to allow students to develop their design and fabrication skills. The second half of the semester was devoted to a team project in which students designed and built a prototype of a toy intended for 9- to 11-year-old children. The toy was required to mimic an animal and generally involved both mechanical and electrical components. The students also were tasked with creating a game that incorporated the toy. For example, one team created a bear, whose jaws were controlled by mechanical levers; the game was to catch beanbag fish that were launched at the bear's mouth. The individual project was heavily scaffolded and included individual training in CAD and the use of machine tools in the shop, as well as in the design process generally. This ensured that all students had a background in the full design and fabrication process before they joined a project team. For the second project, students were asked to identify and share their learning goals with their team, and to create a project plan that allowed each team member to address their individual goals. Team health activities were also scaffolded.

At the LPU, students participated in different sections of the same course, all of which followed the "design, build, test" model and included at least one hands-on team project. Examples of team project assignments include: building an underwater remote-operated vehicle (ROV) that could complete a variety of timed tasks; designing a product for the "real world," in which many students focused on solving problems on campus; or creating an apparatus that enables the use of a bicycle to power a lightbulb. Half of the course credits were devoted to the technical topic, while half of the course was devoted to technical communication, encompassing oral and written communication. Depending on the course section, team members may have created a team contract or rotated weekly through specific team roles, but there were no specific interventions in place regarding team member's task selection or development of confidence or self-efficacy.

Table 1. Research study participants

	Large Public University			Small Private Engineering College		
	Male Students	**Female Students**	**Total**	**Male Students**	**Female Students**	**Total**
Fall 2012	5	3	8	14	16	30
Fall 2013	3	4	7	6	7	13
Fall 2014	1	1	2	1	4	5
Fall 2015	22	15	37	0	0	0
Overall	31	23	54	21	27	48

Forty-eight students from the SPrC and 54 students from the LPU participated in the study. Table 1 summarizes the student participants.

3.2 Data Collection

During the data collection phase, both quantitative data, in the form of pre- and post-course surveys and weekly activity logs, and qualitative data, in the form of post-course interviews, were collected.

The pre-course survey included questions on demographics, Big Five personality traits [45], and prior engineering experience. The pre- and post-course survey included constructs to assess seven different measures of engineering confidence and self-efficacy. First, students rated their (1) confidence in and (2) commitment to completing their engineering degree. A previously-validated Academic Self-Confidence instrument was used to assess students' self-confidence in three different elements of engineering: (3) Open-Ended Problem-Solving, (4) Math and Science Skills and (5) Professional and Interpersonal Skills [46]. Finally, students assessed their (6) Tinkering Self-Efficacy and (7) Engineering Self-Efficacy [47]. For each measure, students rated their agreement on a Likert scale from 1–7 (in the Academic Self-Confidence instrument) or 1–5 (all other instruments).

Weekly activity logs were completed by students to report the time spent on various tasks in the project that week. The students chose from a list of 40 hands-on design tasks, which was derived empirically from a preliminary study done at a small private engineering college (SPrC), one of the institutional contexts of this study. Students also had the opportunity to write in additional tasks. For the analysis presented here, the tasks are organized into two sets of clusters. The first type, the Mastery Clusters, includes tasks that map directly onto items within each of the confidence and self-efficacy instruments described above. Tasks can be included in more than one mastery cluster. For example, the 'communicating with team members' task is included in both the Academic Self-Confidence in Professional and Interpersonal Skills cluster and the Engineering Self-Efficacy cluster. The second type of cluster, Activity Clusters, are groupings of related activities within twelve areas: Brainstorming, Calculations, Communication, Documentation, Hands-On Work, Modeling, Oral Presentations, Project Management, Research, Sketching, Teamwork, and Written Communication.

At the conclusion of the project, a subset of students participated in semi-structured interviews. Students who participated in 75% or more of the weekly logs were first invited to interview; next, female or underrepresented minority students were invited, to over-sample underrepresented groups. Table 2 summarizes the students that participated in interviews.

During the interviews, students were asked questions about their background and their perceptions of engineering, their school, and the class; their team experience; their individual project experience; and about other factors that may affect the development of engineering self-efficacy that were not captured in quantitative survey instruments. A subset of interview questions is included in Table 3.

3.3 Data Analysis

This study employed a concurrent triangulation mixed-methods design, in which the analysis of quantitative data informed the analysis of qualitative data and vice versa [48].

Table 2. Interview participants

	Large Public University			Small Private Engineering College		
	Male Students	**Female Students**	**Total**	**Male Students**	**Female Students**	**Total**
Fall 2012	0	0	0	7	5	12
Fall 2013	1	2	3	2	5	7
Fall 2014	1	0	1	0	1	1
Fall 2015	4	6	10	0	0	0
Overall	6	8	14	9	11	20

Table 3. Sample questions from the semi-structured interview protocol

Background	How did you decide to study engineering?
	So far, how do you feel about your engineering program?
	Is this engineering program what you expected? If so or if not, in what ways?
	What did you like best/least about the course?
Team	Can you describe your teammates?
	For each of your teammates, assign 1-3 roles that they played on the team.
	Can you describe how your team usually made decisions?
Individual Project Experiences	What role did you play on your team? How did you feel about that role?
	What was your favorite activity on the project?
	What were your goals for the course? To what extent did you achieve those goals?
	Was there anything for the project that you wish you did more of? Why do you think you didn't do more of it?
	Was there anything for the project that you did more of than you wanted to? Why do you think you did more of it?
Factors in Confidence/ Self-Efficacy	Did this course change your perceptions of anything? Did it affect how you feel about yourself or about engineering?
	Did you feel that your team trusted you with certain tasks? How did you know?
	Can you give examples of one or two people that you'd like to be like, and why?
	How do people respond to you being in engineering? Can you give an example? Why do you think they respond this way? How do those responses make you feel about being in engineering?

Statistical tests included analyses of variance (ANOVAs), to compare the datasets from each year of the study; paired t-tests to compare students' pre- and post-course measures of engineering confidence and self-efficacy; unpaired t-tests, to compare measures from male and female student groups; and Pearson's correlation tests to determine relationships between students' time spent on different activities, reported confidence or self-efficacy measures, and demographic data. All differences or changes discussed in this paper are significant at a level of $p = 0.05$. In this paper, all confidence or self-efficacy measures are average measures normalized to be out of 1, to reconcile that some metrics used a Likert scale out of 7 and others used a scale out of 5.

Qualitative data was analyzed with a mix of predetermined codes and emergent coding. Predetermined codes were related to the contributors to the development of self-efficacy (mastery experiences, role models, physiological states, social persuasion) and the types of tasks in which students engaged (technical, non-technical). Emergent codes included those related to how students talk what impacts their confidence or self-efficacy: positive changes, negative changes, or how they perceive it relative to other students. In this paper, quotes are provided as illustrative examples, to attempt to explain the findings from the quantitative data. A future publication will focus on more rigorous and comprehensive qualitative findings.

For the purposes of this study, gender was treated as a binary construct, primarily for two reasons. First, students were given the opportunity to self-identify as having a non-binary gender, but nearly all students identified as male or female. Second, most gender-related schemas and stereotypes assume a gender binary; thus, regardless of how students see their own gender identity, they are likely to be 'shoehorned' into a gender binary in their academic environment. Related to this, most of the existing research in engineering education presumes binary gender. Therefore, we considered students as 'men' or 'women' for the purpose of this analysis.

4. Results

4.1 RQ1. How Does Engineering Confidence and Self-Efficacy Compare Between the Two Institutions, For Each Gender?

Some significant differences were observed in self-confidence and self-efficacy measures between women at each of the two institutions. Women at the SPrC began the project course with higher Academic Self-Confidence in Professional and Interpersonal Skills and higher Tinkering Self-Efficacy than their counterparts at the LPU. While the Academic Self-Confidence in Math and Science of women at both institutions were initially indistinguishable, they diverged: by the end of the semester, women at the LPU had higher confidence in Math and Science than their counterparts at the SPrC. Unsurprisingly, therefore, the change in this measure over the semester was also significantly different between the two schools. Finally, a greater increase in Engineering Self-Efficacy was observed for women at the LPU than at the SPrC, although the entering and exiting values were not statistically different ($p = 0.054$ and $p = 0.09$, respectively).

Only one significant difference was observed between the institutions for the male students:

men at the SPrC had a higher exiting Academic Self-Confidence in Open-Ended Problem Solving than those at the LPU.

4.2 RQ2. How Does Engineering Confidence and Self-Efficacy Compare and Change for Students Between the Start and the End of the Project Course?

Students at the SPrC benefited from the project differently, in terms of changes to their engineering confidence or self-efficacy measures (Fig. 1): men experienced a significant increase in Academic Self-Confidence in Open-Ended Problem Solving and women experienced a significant *decrease* in Academic Self-Confidence in Math and Science. There were also a number of significant differences between men and women at the SPrC at the beginning of the course: women started the semester with lower commitment to and confidence in completing their degree and with lower Academic Self-Confidence in Open-Ended Problem-Solving and in Math and Science. At the end of the course, only one significant difference remained: women still had statistically lower Academic Self-Confidence in Math and Science than their male peers.

At the LPU, men only experienced a significant increase in one measure (Academic Self-Confidence in Professional and Interpersonal Skills) while women experienced an increase in several (Academic Self-Confidence in Open-Ended Problem-Solving and in Professional and Interpersonal Skills, Engineering Self-Efficacy and Tinkering Self-Efficacy) (Fig. 2).

Many students at the LPU, in fact, mentioned their work on Interpersonal and Professional tasks throughout the semester in interviews, with some noting how that work made them more confident. For example:

> "I think [the project] made me feel more confident, I guess, as a team leader . . . I was thinking of going into business and this kind of helped me feel like I could manage a group of people out there, if I went into project management".

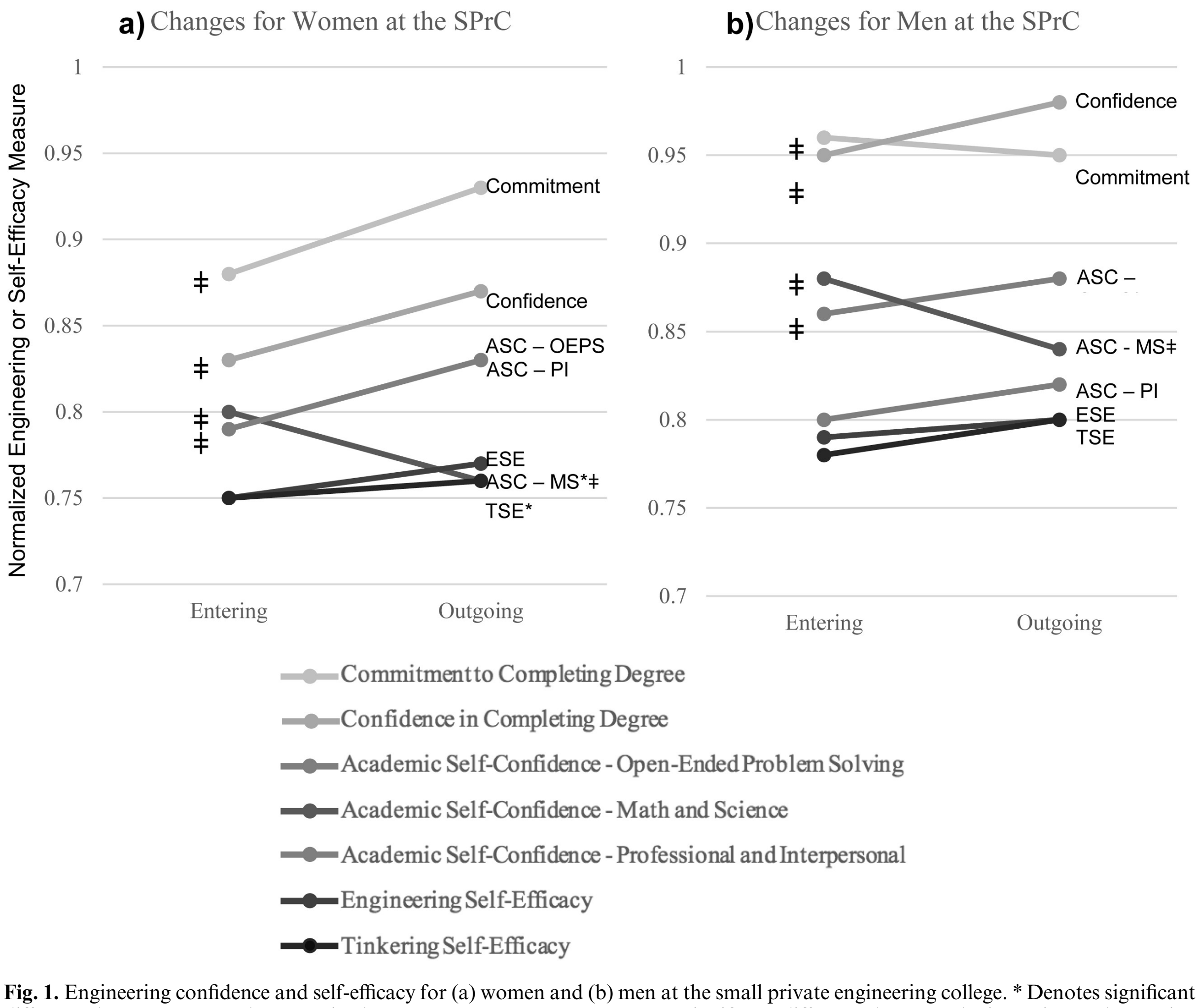

Fig. 1. Engineering confidence and self-efficacy for (a) women and (b) men at the small private engineering college. * Denotes significant difference between men and women in that measure at $p < 0.05$. ‡ Denotes significant difference between the incoming and outgoing measure for that gender at $p < 0.05$.

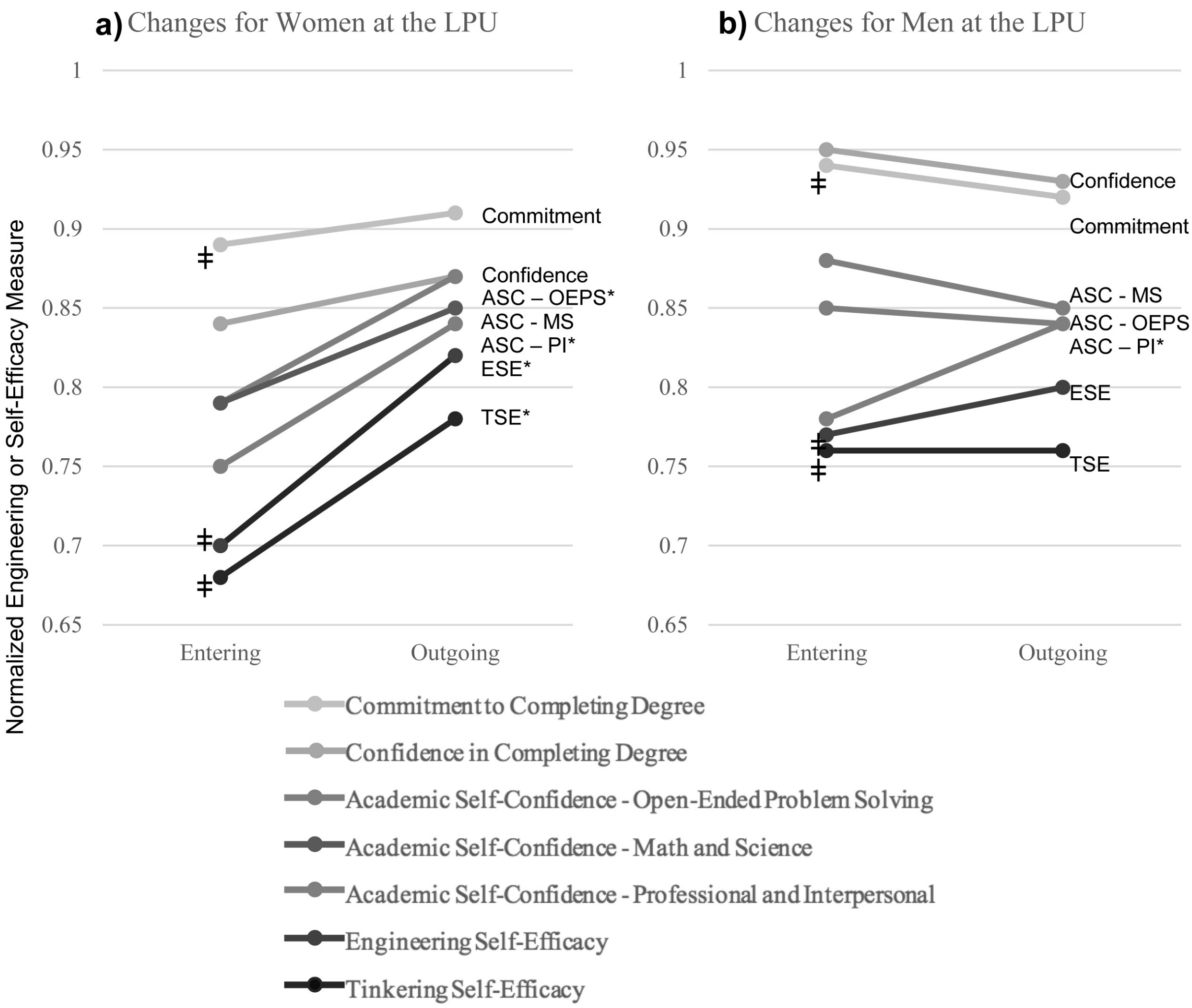

Fig. 2. Engineering confidence and self-efficacy for (a) women and (b) men at the large public university. * Denotes significant difference between the incoming and outgoing measure for that gender at $p < 0.05$. ‡ Denotes significant difference between men and women in that measure at $p < 0.05$.

Although women experienced a significant increase in Tinkering Self-Efficacy and men did not, several male students – but no female students – specifically talked about an increase in their confidence around engineering and building skills. For example:

> "I wasn't really confident in my technical skills in terms of building, but I think after this course I feel a lot more confident in my ability to make something, which I think is good."

At the beginning of the course, men had higher commitment to completing their degree, Engineering Self-Efficacy and Tinkering Self-Efficacy than women, but at the end of the course, there were no significant differences in any measure for male and female students.

However, individual experiences varied, of course, as evidenced by students' interviews. For example, one female student reported that the first-year engineering design class encouraged her to switch *out* of engineering:

> "I wanted it to be a course that would make me go, okay, yeah, this is exactly what I want to do. I want to do engineering. And actually, coincidentally, it didn't. I actually didn't really like it that much, in general."

A male counterpart mentioned that the course made him question being in engineering but because he enjoyed the project activities so much, he decided to persist:

> "[The project] made me completely sure that I want to do engineering; it definitely did throw me around a little, because I almost enjoyed everything I did, from naval to electrical, to the computer science programming . . . kind of made me question honestly what I wanted to do. But it overall made me sure I was doing engineering."

4.3 RQ3. How Are Male and Female Students Spending Their Time Differently in Team Projects?

At the SPU, there were no reported differences in how male and female students spent their time in the project course (Fig. 3). All students spent the

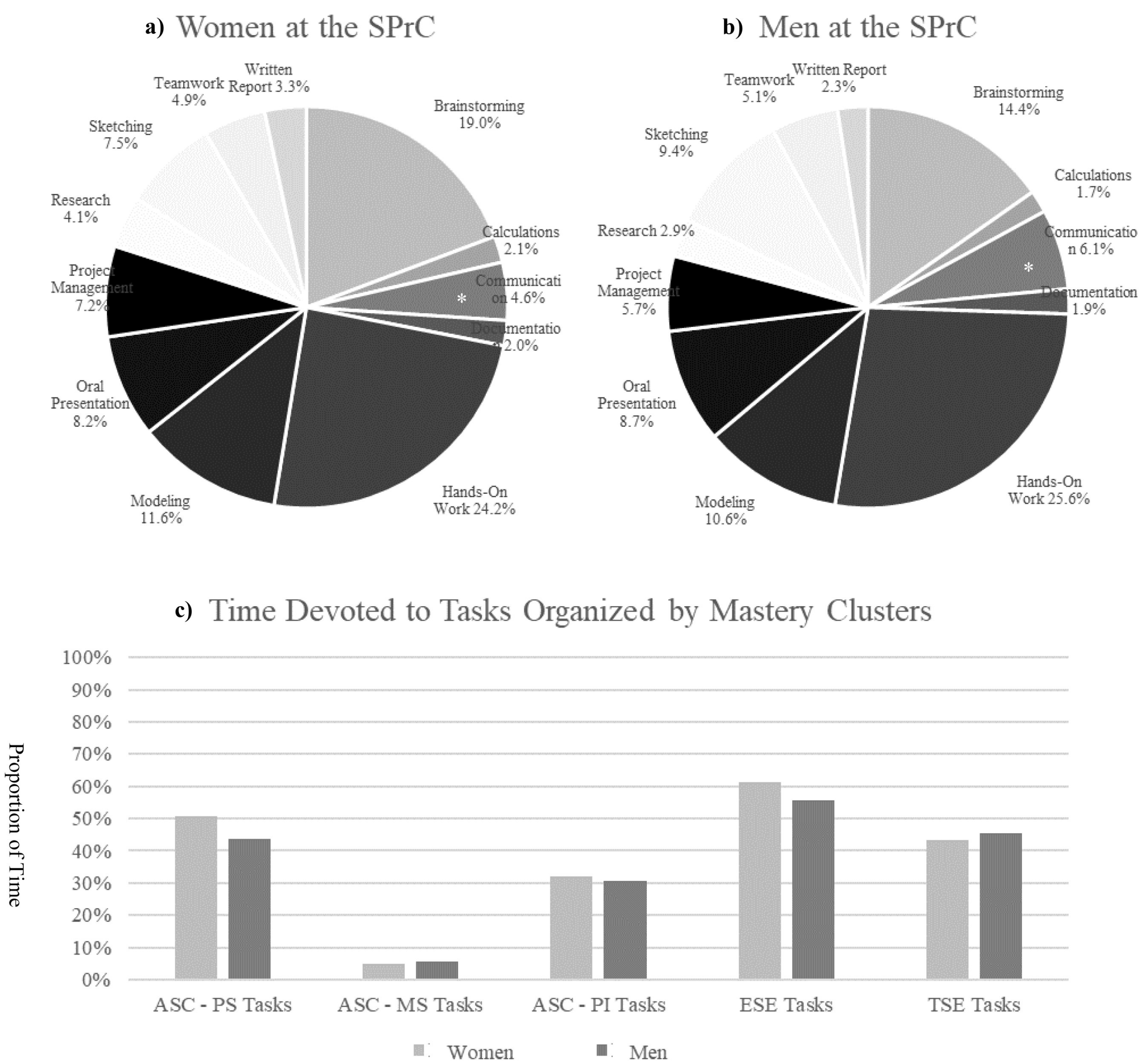

Fig. 3. The proportion of time devoted to different task clusters for women and men at the small private engineering college, in terms of (a) and (b) Activity Clusters and (c) Mastery Clusters. * Denotes a significant difference at $p < 0.05$.

most time on tasks in the Hands-On Work, Brainstorming, and Modeling activity clusters.

Consistent with these findings, both male and female students at the SPrC reported in interviews that they took on both technical and non-technical roles. For example, men and women were equally likely to self-identify as leaders, planners, and builders. A higher proportion of women than men identified as the "CAD person," and more men than women identified as a "helper."

However, when students described their experiences in more detail during the interviews, perceptions that are more in line with gendered stereotypes were revealed. For example, several women expressed regret that they did not spend more time doing technical tasks, despite there being little difference between men and women in time reported as being devoted to technical tasks. Women instead noted that they spent a large amount of time on scheduling, planning, or on "arts and crafts":

> "I definitely feel like I got good experience in teamwork for sure, but I can't say I came out of it with any understanding of how motors work, with any understanding of how to build a mechanical design because we didn't do any of that. So I definitely got a very different experience. I got good at arts and crafts. I learned how to use pipe cleaners very well. So, I mean, my energy went to teamwork, for one thing, and project management which I got to be very good at, but also I feel like a lot of energy went into aesthetic things that isn't necessarily good at teaching me things for the future."

When asked "what part of the project made you really feel like you were learning?" one female student mentioned that she learned the most by *watching* her male teammates do hands-on work:

> "I think watching the guys CAD and helping them assemble everything and watching them as this stuff happened it . . . I learned a lot about mechanisms and stuff and about figuring out how to solve problems kind of thing . . . I thought that was just really interesting, kind of learning how to solve these problems very simply."

At the LPU, students spent the most time on Hands-On Work, Oral Presentations and the Written Report (Fig. 4). There were two significant differences between male and female students: women reported spending less time than men on tasks in the Math and Science activity cluster, and more time on tasks in the Communication activity cluster.

These gender differences observed in the survey data were reflected and amplified in the interviews. As at the SPrC, men and women at the LPU were equally likely to report in interviews that they took on the role of "planner" or "leader". However, a higher proportion of men identified as a "builder", while a higher proportion of women identified as a "communicator". Men and women were equally likely to report having been a "CAD person" (compared to women being *more* likely to be a "CAD person" at the SPrC). In the interviews, several female students at the LPU mentioned performing many of the writing or administrative tasks for their group, often against their preference. For example:

> "I felt like I didn't really choose to be [this role], but everyone would always end up saying, "Okay, can you print this out? Can you make sure that it gets submitted

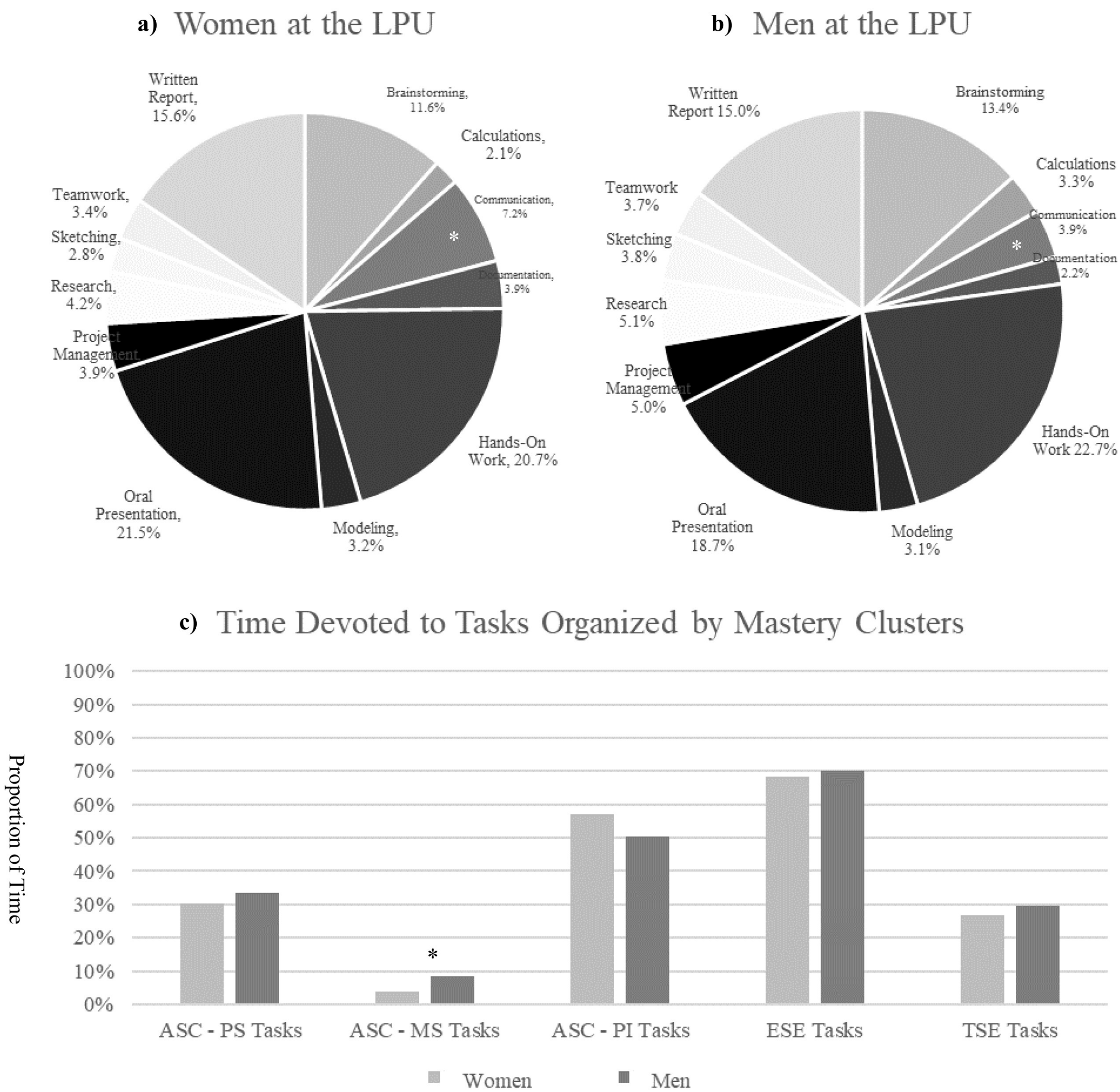

Fig. 4. The proportion of time devoted to the different tasks for women and men at the large public university, in terms of (a) and (b) Activity Clusters and (c) Mastery Clusters. * Denotes a significant difference at $p < 0.05$.

online?" I'd be like, okay, yes, and then that kind of just stuck with me and I would always be the last one to look over everything and turn it in."

Another female student talked about choosing engineering as a major because she wasn't interested in writing:

"Yeah, I'm more of a math person because I just never really liked any of my English classes in high school and middle school so when it came to deciding something I wanted to go away from having to write a lot of papers. So engineering was a good choice."

However, later in the interview, she reported doing most of the writing for the team:

Interviewer: "One reason you wanted to go into engineering is because you don't like writing, but you're ending up doing a lot of the writing for the report."

Student: "Yeah."

Interviewer: "Why do you think that is?"

Student: "I think I volunteered to do it and at the same time it was like all of the introduction and stuff like that. So it's not super hard. I think it would be – I feel like that was more simpler than doing all of the calculation stuff which I don't even 100 percent understand how to come up with all of the center of graphic, center of buoyancy calculation stuff. So I was like okay I'll just do all of the stuff at the beginning and all of the stuff at the end like all of the introductory material. And it was easier for me and I understand it more and that's how I did it. That's the material I covered in the presentation. So I feel more skilled in that."

Although there were few differences between men and women in the time they reported spending on engineering-related tasks, many students still used gendered language when identifying the roles of their teammates. For example, one student mentions that his female teammates took the lead, but he does not define them as leaders:

Student: "They're the ones that, they were less, I guess, shy at the beginning. So they're the ones that kind of took the lead and came up with the ideas, and we just kind of went along with them, I guess."

Interviewer: "Okay. Would you call either or both of them leaders of the group?"

Student: "Not really."

A female student described both a female and male teammate as doing CAD modeling, but when the student was asked to assign roles to these teammates, she assigned "CAD person" to only the male teammate, assigning "artist" and "helper" to the female teammate.

4.4 RQ4. How Does Students' Incoming Confidence or Self-efficacy Level Influence the Tasks That They Take On?

Interestingly, there were several similarities between the women at the LPU and the men at the SPrC. For both groups, the time that they reported devoting to Professional and Interpersonal Tasks and the Written Report was negatively correlated to incoming levels of various measures of engineering confidence and self-efficacy, while these initial measures correlated positively with the proportion of time devoted to Open-Ended Problem-Solving. For women at the SPrC, there were significant positive correlations between their entering levels of multiple measures of engineering confidence and self-efficacy and the time devoted to Math and Science tasks.

4.5 RQ5. Which Tasks Lead to Changes In Engineering Confidence or Self-efficacy?

For all students, there were correlations between the change in their confidence in completing their degree and the proportion of time spent on tasks. For women at the SPrC, the change in confidence in completing their degree correlated positively with the proportion of time spent on Brainstorming. For men at the SPrC, the change in confidence in completing their degree correlated positively with the proportion of time spent on Documentation and the Written Report and negatively with the proportion of time spent on Modeling and on Tinkering tasks. For women at the LPU, the change in confidence in completing their degree correlated *negatively* with the proportion of time spent on Project Management and Written Report. For men at the LPU, change in confidence in completing their degree correlated positively with the proportion of time spent on Professional and Interpersonal tasks and negatively with the proportion of time spent on Hands-On Work and Tinkering tasks.

Also, tasks were correlated with change in Engineering Self-Efficacy only for women at the SPrC: the change in Engineering Self-Efficacy correlated positively with the proportion of time spent on Brainstorming and negatively with the time spent on Math and Science tasks and on Hands-On Work.

At the LPU, there were several correlations between the change in Academic Self-Confidence in Math and Science and the proportion of time devoted to different Activity Clusters and Mastery Clusters. For women, change in Academic Self-Confidence in Math and Science was positively correlated to the proportion of time devoted to Professional and Interpersonal Tasks, Project Management and the Written Report and negatively correlated with Brainstorming, Hands-On Work and Tinkering tasks. For men, change in Academic Self-Confidence in Math and Science was negatively correlated to the proportion of time devoted to Problem-Solving, Research and Sketching. At the SPrC, there were no significant correlations between the proportion of time spent on tasks and the change in Academic Self-Confidence in Math and Science.

At the SPrC, there were several observed correlations between the change in Academic Self-Confidence in Professional and Interpersonal Skills and the proportion of time devoted to different Activity Clusters and Mastery Clusters. For women, change in Academic Self-Confidence in Professional and Interpersonal Skills correlated positively with the proportion of time devoted to Project Management and negatively with Engineering tasks. For men, the change in Academic Self-Confidence in Professional and Interpersonal Skills correlated negatively with the proportion of time devoted to Calculations and positively with the proportion of time devoted to Engineering tasks and Oral Presentation. At the LPU, there was only one significant negative correlation for men: the change in Academic Self-Confidence in Professional and Interpersonal Skills correlated negatively with the proportion of time devoted to Teamwork.

5. Discussion

The data presented here are a snapshot of different types of student experiences in first-year, hands-on engineering design courses from two different institutions. The first thing that is clear is that the overarching academic context (the institution) does impact student task choice and self-efficacy: the observed patterns in student behavior and responses varied between the two institutions, despite being nominally similar populations and courses. In particular, women spent time on different tasks and had different changes in engineering confidence and self-efficacy at each institution. These results suggest that task choice and self-efficacy are sensitive to the learning experience in a way that *interacts* with student demographics, rather than student demographics being the dominant contributor to their experience in a project course; that is, while gender is a factor, the specific effects depend on the academic context. The two learning environments investigated here are two points in the whole space of student engineering experiences and cannot therefore be representative of the whole range of possibilities. While this makes it challenging to generalize about the effects of design courses on self-efficacy, the data presented here does illuminate key takeaways that can inform how instructors shape these learning experiences in order to increase students' engineering confidence and self-efficacy.

5.1 Students Benefit From Spending Time on Non-Gender-Stereotypical Tasks

Some of the correlations between changes in confidence in completing a degree and time devoted to tasks were not specific to the academic environment. For men at both institutions, changes in various confidence measures (Confidence in Completing Degree, Academic Self-Confidence in Math and Science and in Professional and Interpersonal Skills) correlated positively to time spent on non-technical tasks (Documentation, Written Report, Professional and Interpersonal tasks) and correlated negatively to time spent on technical tasks (Problem-Solving, Calculations, Modeling, Tinkering and Hands-On Work). For women, the opposite occurred: a change in confidence in completing their degree correlated negatively with the proportion of time they reported spending on non-technical tasks (Project Management, Written Report). This finding suggests that, regardless of gender, it is beneficial for students to spend more time on tasks that are not stereotypically gendered: men appear to gain confidence in their ability to complete their engineering degree by spending time on tasks associated with teamwork and communication, while women appear to *lose* confidence by spending time on these tasks. Alternatively, of course, this may be a manifestation of declining confidence; in either case, female students focusing on administrative tasks in engineering design courses may be cause for concern.

5.2 Project Experiences Have More Impact on Female Students' Engineering Confidence and Self-Efficacy

Within each institution, men generally had significantly higher levels of engineering confidence and self-efficacy than women at the beginning of the course (see Figs. 1 and 2), consistent with previous research [39, 44, 49]. These gaps closed over the course of the project, with one exception: men at the SPrC still had higher levels of Academic Self-Confidence in Math and Science than their female counterparts. This suggests that women experienced increases in most measures of engineering confidence and self-efficacy throughout the semester, reinforcing previous work that suggests that engaging in team-based project experiences has a beneficial effect on women [16].

5.3 Men Had Similar Project Experiences Regardless of Context…

Students were generally similar to their same-gender peers at both institutions. Men, in particular, had statistically similar entering and outgoing measures of self-confidence (and thus changes in these measures as well) at the two institutions, with one exception: Academic Self-Confidence in Open-Ended Problem-Solving was higher at the end of the course for men at the SPrC than their male peers at the LPU. This may reflect both that open-ended problem-solving skills are specifically developed at the SPrC, and that the pedagogical modes used and the learning experiences that students engage in are effective at increasing self-confidence for men (but not women). This may be because men are more likely to have mastery experiences or that the development of academic self-confidence for women is also colored by other relevant factors, including social affirmation or role models (or, in both cases, the absence thereof).

5.4 ... While Women Had Very Different Experiences at Each Institution

However, there were a few notable differences comparing women at the LPU and SPrC that perhaps illuminate how the differences in context and project experiences could impact confidence or self-efficacy of women in team-based engineering projects. For women at the SPrC, there was a significant positive correlation between multiple initial measures of confidence and time spent on Math and Science tasks, which suggests that more confident women are taking on these technical tasks than their less confident female peers. Women at the LPU started the project course with lower measures than women at the SPrC in two areas (Academic Self-Confidence in Professional and Interpersonal Skills, Tinkering Self-Efficacy), but did experience larger positive changes in two measures (Academic Self-Confidence in Math and Science, Engineering Self-Efficacy).

5.5 Spending More Time on Technical Tasks Could Negatively Impact Female Student's Confidence in Math and Science

Women at the LPU are gaining more confidence (Confidence in Completing Degree, Academic Self-Confidence in Math and Science) by spending *less* time on technical tasks (Tinkering, Hands-On Work) and *more* time on non-technical tasks (Project Management, Written Reports), and are also spending less time than male students on Math and Science tasks in general. However, more confident women in the SPrC are taking on more Math and Science tasks, although women as a whole at the SPrC experienced a *decrease* in Academic Self-Confidence in Math and Science. Both of these findings are counterintuitive, as we'd expect there to be a correlation between taking on a type of task and increase self-confidence or self-efficacy in that area. There are several possible reasons for this paradox.

Students could be experiencing the Dunning-Kruger effect, in which they tend to underestimate their knowledge and ability in a domain as they become more advanced, likely because their greater understanding of the field means that have a better conception of what they don't know [50]. Female students in the LPU project are doing less technical work than their male peers, and thus may be less aware of how much they do not know in terms of Tinkering or Hands-On skills. At the SPrC, women are spending more time on technical tasks, and are perhaps realizing how much they do not yet know, or more specifically, how much they may not know relative to their peers. If one asks oneself, 'how confident am I in my math and science skills?', the idea of 'relative to whom?' is implicit in the question. In theory, the self-efficacy questions are supposed to be 'how confident am I that I can do this specific task?' which should be independent of other people, but an implicit comparison to others may remain.

Another reason could be due to the nature of feedback in design-based courses. In core math and science courses (calculus, physics, chemistry, etc.), the feedback is usually targeted and quantitative, so students have a clear understanding of their progression. At the SPrC, most math and science tasks in students' first-year are within the context of project-based, open-ended courses, while at the LPU, students are concurrently taking traditional calculus and science courses. Thus, women at the SPrC may not be receiving the same kinds of unambiguous, individual feedback on their math and science capabilities (and thus may not experience an increase in confidence in that area) as women at the LPU. Furthermore, in team-based projects, as in most design or open-ended problem-solving contexts, feedback on individual performance is less clear. Students may know how their work products are received, but not how their actual individual skill development has progressed. Instead, perceptions of their progress are likely to be impacted by team dynamics or interactions. Thus, students' perceptions of their skill development may be more sensitive to stereotype threat or implicit bias. In other words, given ambiguous feedback on the design product, men may be more likely to take this feedback as positive affirmation on their technical skills, while women may not.

Finally, this work may be further emphasizing female students' development of confidence or self-efficacy is less impacted by mastery experiences than male students' is. One female student at the LPU, for example, described how she completed hands-on work for the project, but did not acknowledge that she did so or that she learned anything in the process:

> *Female Student*: "So we procrastinated a little bit, and we saved actually building our prototype until, like, the day before, which was our fault, but we thought it wouldn't take that long, and so we went – just the day

before, we were, no. Are we gonna make, really, it was like a box, and we just had to cut out a little hole, so we were, like, 'Oh, it's gonna be so easy.' And so we went and we there for, like, two hours, and then that wasn't the whole time we were there. We were there for two hours."

Interviewer: "In the shop."

Female Student: "Yeah, in the shop. [My team member] was like, 'You guys, I have to go. I have a class.' And we weren't done, and so I don't know how, but [another team member] and I finished that, and neither of us are good with that sort of thing."

Interviewer: "Tell me more about that. You're like 'I don't know how,' but clearly you knew how because you finished it; so, what?"

Female Student: "Well, we were, like, all kind of working together on it, and he had cut everything. We didn't have to do anything really that dangerous, but we had to screw in the walls, I guess you would call it, and make sure that everything was sort of in line. And so we figured it out, and so that was, I think, very proud for us, too, because we really had no experience with that, and we did pretty well with it."

Interviewer: "Right. So were you drilling holes? It was work, right, so drilling holes and then drilling pilot holes and then screwing it together."

Female Student: "Um hm."

Interviewer: "Okay. That's something."

Female Student: "Thank you."

Other studies have also noted that women may be more impacted by other contributors to self-efficacy like social persuasion and vicarious experiences [51]. In the semi-structured interviews, students were asked about these other contributors, such as being asked to identify their role models or explain how people react when they hear they are an engineering student. The analysis of this data will be presented in a future paper.

5.6 Many Other Factors Beyond the Project Course are Impacting Students' Engineering Confidence and Self-efficacy

These findings also emphasize that the first-year design courses are not taught in isolation, and students are impacted by situations outside of this context. Of course, the project experiences at each institution – the team, instructor(s), details of the project assignments, etc. – are different, and those differences can impact students' changes in engineering confidence or self-efficacy or the decisions that they make in the project. But beyond the course, students are having widely varying experiences – both within each institution and in general – that are not captured in the survey data. For example, interpersonal interactions at the school could be impacting students' behavior, specifically, the prevalence or absence of gendered microaggressions or outright harassment. Also, students are concurrently enrolled in other courses that can be impacting their engineering confidence and self-efficacy. One female student at the LPU noted:

"Well, the pre-reqs are definitely hard. It's been a humbling experience coming here and taking courses here at this level. But it's definitely been a good, challenging and interesting in general."

Furthermore, it is important to consider these findings within the context of women in engineering as a whole. It is undeniable that it is more difficult for women to persist in engineering, compared to men, for a number of reasons: being in the minority [2], the field being stereotypically masculine [4], the types of tasks being stereotypically "male" tasks [6], lack of role models, etc. Thus, women who persist in engineering may require higher levels of engineering confidence or self-efficacy than their male peers. In other words, being confident in one's math and science skills, but still spending more time on non-technical tasks (whether that is due to gender norms, personal preference, team dynamics, or other reasons) may be the epitome of the female engineering student experience. The results from this study may therefore be telling only part of the story: while confidence and task choice are related, there are likely to be many other factors that affect both student confidence and the activities they undertake, and these effects may be significant. Regardless, while it *is* important that students develop engineering confidence and self-efficacy through project courses, it is also important that they develop the broad base of skills that is necessary to practice and succeed in engineering. Thus, ideally, women and men would both be equally engaged in the non-technical and technical aspects of projects, so they are prepared to continue on to their other classes and eventually, to practice. This may involve instructors consciously shaping the learning experiences to make sure that students have the opportunity to practice these skills, as they did in both of the institutions described here, via individual skill laboratories or projects before commencing the group projects.

5.7 Quantitative Findings May Not Represent Gendered Behaviors That Are Present

The language used in the interviews, as a whole, demonstrates that it is not enough to compare activity logs or quantitative data. Despite many reassuring quantitative findings (closes in gender gaps in engineering confidence or self-efficacy, the same amount of time devoted to different tasks, etc.), the interviews did reveal that certain issues may arise in team projects between male and female students.

For example, at the SPrC, men and women spent the same proportion of time on each project task.

At the LPU, women spent significantly less time on math and science tasks and more time on communication tasks than their male counterparts. This finding suggests that, for the most part, there is very little gendered behavior in teams in terms of task allocation. However, although the quantitative results suggest that there is very little gendered division of tasks, there was still a great deal of gendered discussion in the post-project interviews. In the interviews, students were asked to describe the tasks that they took on, and to give their reasons why. Women often were described as taking on the "writer" role for their team, both when self-reporting and when students described their female teammates, despite there being no significant difference between male and female students in terms of the time they devoted to writing. Sometimes, women stated that they took on these tasks because they enjoyed writing, but they also mentioned being reluctant to do more hands-on work for fear of letting down the team. One male student at the LPU described one of his female teammates as having appointed herself the writer, despite being capable of doing more technical tasks:

> "And then there was [my female teammate]. She's really smart, but she seemed to think she knew nothing about engineering or how to go about this. And she pretty much isolated herself to writing from the get-go. She said, 'All I really know how to do is write and edit, so I'll be doing that.' "

Similarly, more men were described as being "builders" or "CAD people" despite there being no significant difference in the time that men or women devoted to those tasks.

5.8 Engineering Confidence and Self-Efficacy May Not Increase Monotonically

Despite our hypothesis that project-based learning would increase students' engineering confidence or self-efficacy, only one group (women at the LPU) experienced multiple positive and significant changes. Men at the LPU experienced an increase in one confidence measure (Academic Self-Confidence in Professional and Interpersonal Skills). Women at the SPrC, however, experienced only one significant change: a *decrease* in Academic Self-Confidence in Math and Science. Although one might expect that self-efficacy would increase over time, as student abilities are developed, previous quantitative work on academic self-confidence [39, 49] suggested that it does not increase monotonically over the four years of engineering school, even for committed and successful students.

There are several possible reasons for this. Students may be calibrating their confidence and self-efficacy relative to their peer group, and this might manifest in two ways. First of all, as students transition to the first year of an engineering program, they may go from being among the more advanced students in math and science in their school to being more 'average', and their self-conception of their ability may fall; this may explain the drop in Academic Self-Confidence in Math and Science of the female students at the SPrC over their first semester observed in this study. Second, as student skills and abilities develop in lockstep with the students around them, their level of confidence remains unchanged relative to their peers. Another factor could be, as described previously, the Dunning-Kruger effect. In practice, of course, it seems probable that all three of these factors (and perhaps others) would contribute to uneven increases in measures of academic self-confidence and self-efficacy.

Although the project experiences did not significantly positively impact all students' confidence or self-efficacy, this does not mean that the project experiences were not valuable. There are many possible reasons for a lack of effect. At the SPrC, for example, one intervention is already in effect: students are asked to articulate their learning goals for the project, and then teams are required to create project plans that allow each student to make progress towards these goals, and student reports indicate that it affects the types of tasks that they engage in [26, 52]. This is likely a significant contributor to women and men at the SPrC spending the same amount of time on technical and non-technical tasks. The projects at both institutions are also carefully scaffolded to ensure some level of student success. And surveys can't capture the full reality of the student experience, particularly when they are focused on a single course.

Also, it is not necessarily negative if students' self-efficacy does not always monotonically improve. In this paper, we use the development of self-efficacy as a primary metric for students in their engineering programs. Historically, student activities within a course (i.e. mastery experiences) have been the specific purview of educators, given that it is one element of the educational experience that can be controlled. But even if students don't experience an increase in self-efficacy, they are still likely learning engineering principles and developing their skills. Also, there are other important aspects of student development (such as identity, sense of belonging) that students may gain from projects even if their engineering confidence or self-efficacy does not steadily increase.

6. Conclusion

This paper presented results of a multi-year study, encompassing data from students enrolled in a first-year engineering design project course at two different institutions. Through the completion of pre- and post-course surveys, weekly activity logs, and semi-structured interviews, we observed that students' engineering confidence and self-efficacy changed over the course of the project, what tasks students completed in the team-based project, the relationship between students' confidence levels and the activities that they took on, and how these experiences varied for male and female students.

There are limitations to this study. Although this work presents two quite different project contexts, the work here is not reflective of the full range of first-year project experiences. Also, we recognize that self-efficacy and mastery experiences cannot be fully measured or assessed using quantitative instruments. For example, "time on task" may not always be evidence that students are engaged in mastery experiences. For example, a student who is skilled in CAD may take on the bulk of the modeling work for their team, and thus spend several hours in the program. A novice may spend the same amount of time on CAD, but feel like they are 'floundering', finding it to be frustrating and unproductive. In the latter case, the student may still spend a large proportion of time on CAD, without feeling like it was a "mastery experience" (even if they were engaged in the work and their skills were increasing).

Despite these limitations, one implication of this work is that projects *can* positively impact female students more than their male peers, but it depends greatly on context; our findings suggest that women may be more sensitive to their learning environment than their male counterparts. While men at each institution had fairly similar experiences, in terms of changes in engineering confidence and self-efficacy, the experience for women at each institution was noticeably different. At the LPU, women did experience a significant increase in many engineering confidence and self-efficacy measures over the course of the project, despite spending less time on Math and Science tasks than male students. Confidence changes for women at the LPU also negatively correlated with time spent on some hands-on, technical tasks and positively correlated with some non-technical tasks, which implies that women's engineering confidence or self-efficacy may benefit from spending time on the technical components of engineering projects, or that these are both correlated with a common factor. Women at the SPrC, however, experienced a *decrease* in math and science confidence over the course of the project, reflecting the influence of factors other than mastery experiences on self-efficacy (in this case, likely an interaction of gender, pedagogical modes, and peer group).

This work provides additional evidence that projects are not a one-size-fits-all scenario, reinforcing the implication that educators must be mindful of the individual student experience. For example, although students were spending generally the same proportion of time devoted to different tasks, the project still impacted them differently, suggesting that gender and the larger academic environment (as well as the details of the project course) were factors. This suggests that educators and institutions may want to consider how both course experiences and the institutional environment affect students' motivation, engagement, and confidence, particularly for female students, since the project and university context can drastically impact changes in engineering confidence and self-efficacy, and thus, ultimately, how students work in teams, develop important skills, and persevere in engineering.

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Laura J. Hirshfield is a Diversity, Equity and Inclusion Lecturer in the College of Engineering at the University of Michigan, situated within the chemical engineering department. Her research interests lie in contributing to better understanding of students' experiences in diverse project teams.

Debbie Chachra is a Professor of Engineering at Olin College of Engineering. Her education-related research interests include self-efficacy, design, intrinsic motivation, and gender. She speaks and consults on curricular design, student-centered learning, and gender and STEM.