The Making of an Innovative Engineer: Academic and Life Experiences that Shape Engineering Task and Innovation Self-Efficacy

Dr. Mark Schar, Stanford University

The focus of Mark's research can broadly be described as "pivot thinking," the cognitive aptitudes and abilities that encourage innovation, and the tension between design engineering and business management cognitive styles. To encourage these thinking patterns in young engineers, Mark has developed a Scenario Based Learning curriculum that attempts to blend core engineering concepts with selected business ideas. Mark is also researches empathy and mindfulness and its impact on gender participation in engineering education. He is a Lecturer in the School of Engineering at Stanford University and teaches the course ME310x Product Management and ME305 Statistics for Design Researchers.

Mark has extensive background in consumer products management, having managed more than 50 consumer driven businesses over a 25-year career with The Procter & Gamble Company. In 2005, he joined Intuit, Inc. as Senior Vice President and Chief Marketing Officer and initiated a number of consumer package goods marketing best practices, introduced the use of competitive response modeling and "on-the-fly" A|B testing program to qualify software improvements.

Mark is the Co-Founder and Managing Director of One Page Solutions, a consulting firm that uses the OGSP® process to help technology and branded product clients develop better strategic plans. Mark is a member of The Band of Angels, Silicon Valley's oldest organization dedicated exclusively to funding seed stage start-ups. In addition, he serves on the board of several technology start-up companies.

Dr. Shannon Katherine Gilmartin, Stanford University

Shannon K. Gilmartin, Ph.D., is a Senior Research Scholar at the Michelle R. Clayman Institute for Gender Research and Adjunct Professor in Mechanical Engineering at Stanford University. She is also Managing Director of SKG Analysis, a research consulting firm. Her expertise and interests focus on education and workforce development in engineering and science fields. Previous and current clients include the American Chemical Society, the Anita Borg Institute for Women and Technology, California Institute of Technology, the College of Natural Sciences and Mathematics at California State University Fullerton, the Office of the Vice Provost for Graduate Education at Stanford University, the School of Medicine at Stanford University, and the School of Fisheries and Ocean Sciences at the University of Alaska, Fairbanks.

Beth Rieken, Stanford University

Beth Rieken is a PhD Candidate at Stanford University in the Mechanical Engineering Department. She is in the Designing Education Lab advised by Prof. Sheri Sheppard. Her work focuses on fostering mindful awareness, empathy and curiosity in engineering students. Beth completed a BS in Aerospace Engineering from the University of Virginia in 2010 and a MS in Mechanical Engineering from Stanford in 2012.

Dr. Samantha Ruth Brunhaver, Arizona State University

Samantha Brunhaver is an Assistant Professor of Engineering in the Ira A. Fulton Schools of Engineering at Arizona State University. Dr. Brunhaver joined Arizona State after completing her M.S. and Ph.D. in Mechanical Engineering at Stanford University. She also has a B.S. in Mechanical Engineering from Northeastern University. Dr. Brunhaver's research examines the career decision-making and professional identity formation of engineering students, alumni, and practicing engineers. In addition, she conducts studies of new engineering pedagogy that help to improve student engagement and understanding.

Dr. Helen L. Chen, Stanford University

Helen L. Chen is a research scientist in the Designing Education Lab in the Department of Mechanical Engineering and the Director of ePortfolio Initiatives in the Office of the Registrar at Stanford University. Chen earned her undergraduate degree from UCLA and her Ph.D. in Communication with a minor in Psychology from Stanford University. Her current research interests include: 1) engineering and entrepreneurship education; 2) the pedagogy of ePortfolios and reflective practice in higher education; and 3) redesigning the traditional academic transcript.

Dr. Sheri Sheppard, Stanford University

Sheri D. Sheppard, Ph.D., P.E., is professor of Mechanical Engineering at Stanford University. Besides teaching both undergraduate and graduate design and education related classes at Stanford University, she conducts research on engineering education and work-practices, and applied finite element analysis. From 1999-2008 she served as a Senior Scholar at the Carnegie Foundation for the Advancement of Teaching, leading the Foundation's engineering study (as reported in Educating Engineers: Designing for the Future of the Field). In addition, in 2011 Dr. Sheppard was named as co-PI of a national NSF innovation center (Epicenter), and leads an NSF program at Stanford on summer research experiences for high school teachers. Her industry experiences includes engineering positions at Detroit's "Big Three:" Ford Motor Company, General Motors Corporation, and Chrysler Corporation.

At Stanford she has served a chair of the faculty senate, and recently served as Associate Vice Provost for Graduate Education.

The Making of an Innovative Engineer: Academic and Life Experiences that Shape Engineering Task and Innovation Self-Efficacy

Abstract

This research paper presents the results of a study that uses multivariate models to explore the relationships between participation in learning experiences, innovation self-efficacy, and engineering task self-efficacy. Findings show that many engineering students participated in learning experiences that are typically associated with engineering education, such as taking a shop class or engineering class in high school (47%), taking a computer science (81%) or design/prototyping (72%) class as an undergraduate, working in an engineering environment as an intern (56%), or attending a career related event during college (75%). Somewhat surprisingly, given the rigors of an engineering curriculum, a significant number of students participated in an art, dance, music, theater, or creative writing class (55%), taken a class on leadership topics (47%), and/or participated in student clubs outside of engineering (44%) during college. There also were important differences in rates of participation by gender, underrepresented racial/ethnic minority status, and first generation college student status.

Overall prediction of engineering task self-efficacy and innovation self-efficacy was relatively low, with a model fit of these learning experiences predicting engineering task self-efficacy at (adjusted r^2 of) .200 and .163 for innovation self-efficacy. Certain patterns emerged when the learning experiences were sorted by Bandura's Sources of Self-Efficacy. For engineering task self-efficacy, higher participation in engineering mastery and vicarious engineering experiences was associated with higher engineering task self-efficacy ratings. For the development of innovation self-efficacy, a broader range of experiences beyond engineering experiences was important. There was a strong foundation of engineering mastery experiences in the innovation self-efficacy model; however, broadening experiences beyond engineering, particularly in the area of leadership experiences, may be a factor in innovation self-efficacy.

These results provide a foundation for future longitudinal work probing specific types of learning experiences that shape engineering students' innovation goals. They also set the stage for comparative models of students' goals around highly technical engineering work, which allows us to understand more deeply how "innovation" and "engineering" come together in the engineering student experience.

Key Concepts: *self-efficacy, engineering task self-efficacy, innovation self-efficacy, learning experiences, academic pathway*

1.0 Introduction

This study provides an initial view of learning experiences that are associated most strongly with engineering students' engineering and innovation self-efficacy, two domains of great interest to recent work in engineering education (Gilmartin et al. 2017). The data for this research come from an NSF-funded initiative called Epicenter (2013) that aimed to better understand the conditions that may encourage engineering students to be more entrepreneurial and innovative. Among Epicenter's several research projects is an ongoing longitudinal survey study of the development of engineering students' career goals around innovation and engineering, referred to as the Engineering Majors Survey (EMS - 2016). The EMS study follows a nationally representative sample of engineering students from their undergraduate experiences through graduation and into the workplace (Gilmartin et al. 2017). Within this survey are measures of engineering task self-efficacy and innovation self-efficacy, as well as 39 background learning experiences and extra-curricular activities spanning high school through undergraduate education, which form the basis for this analysis.

2.0 Background

This research is at the intersection of three important areas of study: self-efficacy, (learning-based) sources of self-efficacy, and the measurement of self-efficacy.

2.1 Self-Efficacy and Social Cognitive Career Theory

Defined as an individual's belief in their ability to implement behaviors necessary to produce specific outcomes (Bandura 1995), self-efficacy has been shown to be an important predictor for a wide variety of positive outcomes (e.g., Bandura 2004, Caprara and Steca 2005, Scholz et al. 2002, Stajkovic and Luthans 1998, Zimmerman 2000), and has proven a useful indicator of academic major selection and performance and career choice (Lent, Brown, and Larkin 1986). Lent et al. developed a predictive model for career choice that is importantly influenced by self-efficacy. This model is Social Cognitive Career Theory (SCCT, see Figure 1) and it provides a framework for understanding, explaining, and predicting the processes through which people develop occupational choice (Lent, Brown, and Hackett 1994; Lent and Brown 2006). The SCCT model has proven to be useful in predicting career choice among post-secondary students, including engineering students (Lent et al. 2005, 2007).

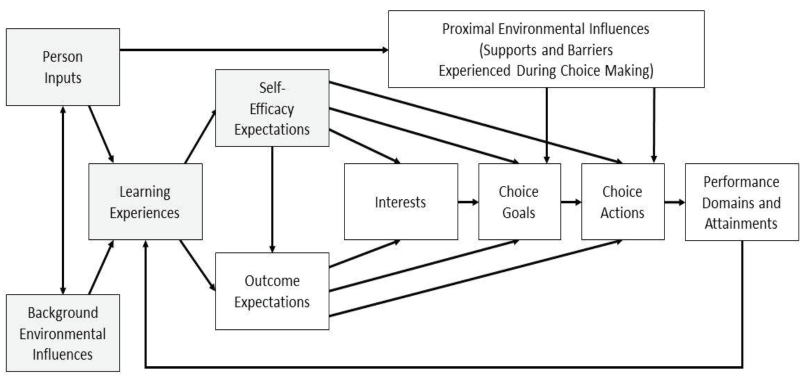

Figure 1- Lent's (1994, 2006) Social Cognitive Career Theory (SCCT) model. Shaded nodes are included in this study.

SCCT posits that vocational or career choice is a function of several social-cognitive variables, such as self-efficacy, outcome expectations, interests and goals. Importantly, the SCCT framework suggests that self-efficacy is a result of a combination of person inputs, background environmental influences and learning experiences[1]. It is this connection that this paper is fundamentally exploring, as part of a larger effort to explain innovative career goals as part of the broader EMS study design (Gilmartin et al. 2017).

2.2 Bandura's Sources of Efficacy Beliefs

Bandura (1995) provides guidance on likely the sources of individual efficacy beliefs. He indicates there are four sources of efficacy beliefs – mastery experiences, vicarious experiences, social persuasion, and positive physiological and emotional states.

Mastery Experiences – Bandura (1995) describes mastery experiences as "the most authentic evidence

[1] In the model for this paper, "person inputs" include age, gender, college GPA, URM and first generation college status; "background environmental influences" include family income and post-secondary school environment in terms of size of the engineering school and Carnegie Classification status.

of whether one can muster whatever it takes to succeed" where successful experiences "build a robust belief in one's personal efficacy" and failures "undermine it" (p. 3). Mastery experiences help acquire "the cognitive, behavioral and self-regulatory tools for creating and executing appropriate courses of action" (p. 3). In the context of engineering task self-efficacy, mastery experiences may involve engineering specific coursework, direct hands-on experiences with engineering tasks such as building, prototyping and design, and engineering work experience through an internship.

Vicarious Experiences – Bandura describes this source of creating and strengthening efficacy as the influences provided by "social models" through relevant vicarious experiences. Bandura (1995) describes these vicarious experiences as "seeing people similar to themselves succeed by perseverant effort [and raising] observer's beliefs that they, too, possess the capability to master comparable activates" (p. 4). There is also an element of aspiration to these vicarious experiences as students "seek proficient models who possess the competencies to which they aspire." (p. 4) In the context of engineering task self-efficacy, vicarious experiences may involve attending a presentation on innovative engineering activity in the workplace, listening to others who have experience that may be valuable in the future (such as attending leadership seminars), and experiencing workplace success through the perspective of others like accomplished entrepreneurs.

Social Persuasion – This source of efficacy involves verbal persuasion "that [individuals] possess the capabilities to master given activities [and] are likely to mobilize greater effort to sustain it than if they harbor self-doubts and dwell on personal deficiencies" (Bandura 1995, p. 4). In the context of engineering task self-efficacy, social persuasion may typically occur in the context of social groups or activities like participation in a robotics or engineering competition where work is done in teams, or through involvement or leadership of student clubs and organizations engaged in engineering activity.

Positive Physiological and Emotional States – Finally, Bandura (1995) suggests that physiological and emotional states play an important role in judging one's capabilities. Often students "interpret their stress reactions and tension as signs of vulnerability to poor performance" while "mood also affects people's judgements of their personal efficacy" (p. 4). This domain is perhaps most difficult to operationalize, but we posit that activities outside of engineering-related mastery, vicarious, or social experiences can still be classified as influencing physiological states; examples include sports, experience with the arts, and involvement in study abroad.

2.3 Measuring Engineering Task and Innovation Self-Efficacy

In this study, the dependent variables are self-efficacy measures (or scales): Engineering Task Self-Efficacy and Innovation Self-Efficacy. The background and construction of these variables are described in the EMS Technical Report (Gilmartin et al. 2017) and summarized below.

Engineering Task Self-Efficacy (ETSE) - ETSE is designed to measure confidence in one's ability to perform integral technical engineering tasks. For this measure, we drew from Fouad and Singh's (2011) work on engineering career outcomes, and the items in our scale, based on Fouad and Singh's instrumentation, were initially adapted to the Pathways of Engineering Alumni Research Survey (Brunhaver et al. 2013). The scale is composed of five items that were identified through factor analysis of a longer list of engineering task items. The items selected include: 1. *Design a new product or project to meet specified requirements*, 2. *Conduct experiments, build prototypes, or construct mathematical models to develop or evaluate a design*, 3. *Develop and integrate component sub-systems to build a complete system or product*, 4. *Analyze the operation or functional performance of a complete system*, and 5. *Troubleshoot a failure of a technical component or system*. Respondents rated confidence in their ability to perform these tasks on a scale of "not confident" (0) to "extremely confident" (4), and resulted in a total sample mean ($\bar{x}$) of 2.42 (σ .84) and an acceptable Cronbach's alpha (α .88).

Innovation Self-Efficacy (ISE) – In recent years, there has been increasing scholarship around engineering innovativeness (see Ferguson and Ohland 2012; Gerber et al. 2012) and the measurement of engineering innovativeness (Menold et al. 2016). The innovation self-efficacy scale used in this paper ("ISE.5" – see Schar et al. 2017) is drawn from the work of Dyer et al. (2008) and their study of the innovative traits of the entrepreneur, familiar to many through the popular book *The Innovator's DNA* (Dyer, Gregersen, and Christensen 2011). Dyer et al. identified 19 items in four constructs that described the innovative entrepreneur. These items were converted to relevant language for students and tested among engineering students; then, using factor analysis, Schar et al. reduced the items from the original 19 to 5 items, without sacrificing the validity or reliability of the original Dyer et al. measure.

The resulting ISE.5 scale includes: 1. *Ask a lot of questions*, 2. *Generate new ideas by observing the world*, 3. *Experiment as a way to understand how things work*, 4. *Build a large network of contacts with whom you can interact to get ideas for new products or services* and 5. *Connect concepts and ideas that appear, at first glance, to be unconnected*. Respondents rated confidence in their ability to perform these tasks on a scale of "not confident" (0) to "extremely confident" (4), resulting in a total sample mean ($\bar{x}$) of 2.62 (σ .74) and an acceptable Cronbach's alpha (α .78).

2.4 EMS Activities and Learning Experiences

A major aim of the EMS is to better understand how engineering students make career choices that involve innovative work, with a particular focus on entrepreneurship. The activities and learning experiences under study supported Bandura's four categories of "sources of efficacy" and tilted toward activities that might contribute to engineering task or innovation self-efficacy and related post-graduation career choice pathways. The activities and experiences are by no means an exhaustive list and leave out some obvious and important activities (like sports or Greek life participation); however, they are specifically relevant to the objective of the EMS study.

The resulting 39 activities include a broad range of measures relating to engineering students' learning experiences, sorted by Bandura's categories of Sources of Self-Efficacy in Appendix 1. Most of these activities touched on elements of innovation and entrepreneurship, while others reflected more general aspects of the engineering student experience that may bear on students' career plans (see Brunhaver et al. 2012; Lichtenstein et al. 2010; Sheppard et al. 2010). These learning experiences and activities were presented in roughly chronological order (high school to undergraduate) on the survey instrument.

In terms of students' curricular and co-curricular learning experiences, we asked about their involvement in seven categories of activities in high school (HS) and/or college (UG): taking arts-related courses (HS/UG), taking courses on computer programming/science (HS/UG), taking shop or engineering courses (HS), taking design-related courses (UG), participating in a robotics competition (HS), participating in STEM-related summer camps, research, or internships (HS), and learning about and doing things relevant to entrepreneurship, business, and/or leadership (HS/UG). Also as part of students' more general college experiences, we asked if they had interacted with non-engineering students as part of their coursework, conducted research with a faculty member, worked in a professional engineering environment as an intern/co-op, held a work-study or other type of job to help pay for their college education, and participated in study abroad. (In a separate set of questions, the EMS asked about students' majors, concentration areas within majors, minors, and certificates --see Cao et al. 2016 for detailed analysis of these items.)

We then presented a list of 20 extra-curricular college activities that students may have been involved in, turning to University Innovation Fellows' Landscape Inventories (2017) for guidance on what to include on the survey. Examples include *"entering a design or invention competition"* and *"making use of a maker space/design or inventors studio/prototyping lab"*. The working hypothesis was that greater participation rates across (some grouping of) these types of activities would be positively associated with students' innovation attitudes and outcomes (see also Dungs 2016).

3.0 Research Questions
This paper addresses two research questions:

- **Research Question 1 (RQ1):** What are the most common high school and undergraduate experiences of engineering students and how does this vary by gender, underrepresented racial/ethnic minority status, and first generation college student status?
- **Research Question 2 (RQ2):** How do these experiences predict students' self-reported engineering task self-efficacy and innovation self-efficacy?

4.0 Methods
In Winter-Spring 2015, the baseline Engineering Majors Survey ("EMS 1.0") was distributed to over 30,000 engineering junior and senior students at a stratified quasi-random sample of 27 engineering schools throughout the US. In total, 7,197 responses were collected, and after screening for Junior, Senior and 5th Year students and cleaning limited data responses, a total of 5,819 respondents composed the analysis data set for this study. The analysis data set contained 96.5% complete data. It was determined that the missing data were missing completely at random (Allison 2009) and multivariate imputation by chained equations (van Buuren and Groothuis-Oudshoorn 2011; Manly and Wells 2015) was used with predictive mean matching and 5-iterations to complete the data set. The complete study protocol is described in the EMS Technical Report (Gilmartin et al. 2017).

Demographic data were collected from each respondent, including age, grade-level, gender (male/female), underrepresented racial/ethnic minority (URM) status, and first generation college (FGC) status.[2] In addition, respondents self-reported grade point average and family income level. The enrollment size and Carnegie Classification of the engineering school for each respondent were merged into the final survey dataset. An overview of the sample demographics is shown in Table 1.

Table 1 - Overview of Study Sample Demographics

	Sample	Gender		Minority Status		Academic Year		
	Total	Female	Male	URM	FGC	Junior	Senior	Fifth-Year Senior or More
n	5,819	1,722	4,097	807	932	2,714	2,384	721
% Total	100%	30%	70%	14%	16%	47%	41%	12%

[2] For the purposes of this study, underrepresented minority (URM) is defined as any respondent who indicated a Latino/a, African American, Native American or Pacific Islander race or ethnicity. First Generation College (FGC) is defined as any respondent whose parents(s)/guardian(s) had less post-secondary education than an Associate degree. There are many possible definitions of a first generation college student (see Choy 2001; Auclair et al. 2008; Toutkoushian, Stollberg, and Slaton 2015) and this definition is regarded as more expansive.

Activity participation was operationalized as a binary variable[3] – "*participated*" (1), "*did not participate*" (0) – and participation rate is expressed as a percent, i.e., the percent of respondents who self-reported participation in any event. Given the large sample size (greater than 300+ responses), differences in sample means were measured using Cohen's *d* effect size (Cooper, Hedges, and Valentine 2009), with > .20 considered a small significant difference, >.50 a medium difference and > .80 a larger difference (UCLA: Statistical Consulting Group 2016). In this analysis, the dependent variables (ETSE and ISE.5) are measured on a Likert-scale (0-4) and are considered continuous, the predictor variables (participation rates and demographic markers) are binary, so multiple linear regression (versus logistic regression) is appropriate (Krathwohl 2009).

We assessed the explanatory variables using two methods – stepwise regression and a technique called the Pratt "product measure" (PPM). The PPM approach is a method for assigning a relative value to each explanatory variable which is the product of the regression coefficient for that variable and the correlation of the explanatory variable with the response variable. This technique was theoretically defined by Pratt (1987) and later confirmed by Bring (1996). The value of the Pratt "product measure" approach is that the researcher can set a cut-off for relative importance based on interpretation of the theoretical model. Since PPMs are very small numbers, the PPM values have been fitted to a normal distribution curve using the variable mean (μ) and standard deviation (σ) resulting in a "PPM Index" that ranges from 0 to 100, where 0 is about -3 σ and 100 is +3 σ from the PPM mean.

5.0 Results

Research Question 1 (RQ1): What are the most common high school and undergraduate experiences of engineering students and how does this vary by gender, underrepresented racial/ethnic minority status, and first generation college student status?

5.1 Activity Participation Rates

Looking back to **high school**, nearly three-quarters of engineering students (73%) reported that they had participated in a class involving *art, dance, music, theater or creative writing*, the largest participation rate of any activity, as shown in Table 2. This participation rate followed by activities more closely associated with engineering study - *taking a shop or engineering class* (47%), and *learning computer programming* (31%). Slightly less than a quarter of students (24%) report some learning experience with *entrepreneurship*, and roughly 1 in 10 (11%) report involvement in a *robotics competition*. There are some notable gender differences: women are more likely to report involvement in the arts (85% vs. 68%) and men report more involvement in shop classes (52% vs. 33%) and computer programming (35% vs. 23%).

When we look at the **college experience on the curricular front** (undergraduate coursework) for 5 of the 7 coursework areas, over half of the students indicated exposure to these areas, with no differences in level of exposure by gender (or URM and FGC demographics) for all seven items. Interestingly, *working with students from non-engineering majors* and *computer science* coursework are virtually ubiquitous among engineering majors, with 85% and 81% reporting exposure, respectively, while just slightly less report experience with *designing and prototyping* (72%). Least common is exposure to business and entrepreneurship topics (35%).

[3] For some participation questions *"don't know"* was offered as an option and these responses were coded as *"did not participate"*.

Table 2. Participation in selected background and academic experiences by key demographic groups

Activity List (Sorted by Total Participation Rate) n =	**Total** 5,819	**Male** 4,097	**Female** 1,722	***d***	**URM** 807	**≠** 5,015	***d***	**FGC** 932	**≠** 4,887	***d***
During high school did you …										
Take art, dance, music, theater, creative writing class	73%	**68%**	**85%**	**.38**	74%	73%	.03	67%	74%	.16
Take a shop class or engineering class	47%	**52%**	**33%**	**.39**	**38%**	**48%**	**.21**	52%	46%	.13
Learn computer programming	31%	**35%**	**23%**	**.25**	31%	31%	.01	29%	32%	.05
Learn about entrepreneurship	24%	**27%**	**18%**	**.20**	25%	24%	.01	24%	24%	.01
Attend science, math, engineering summer camp	22%	**19%**	**28%**	**.22**	23%	22%	.03	**15%**	**23%**	**.21**
Start or co-found a club, organization, or company	16%	16%	17%	.01	17%	16%	.04	13%	17%	.09
Intern at science, math, engineering organization	12%	12%	13%	.03	14%	12%	.05	9%	13%	.13
Participate in a robotics competition	11%	12%	9%	.08	11%	11%	.01	9%	12%	.08
While an undergraduate, have you …										
Worked in an engineering environment as an intern/co-op	56%	54%	60%	.13	**41%**	**58%**	**.35**	**46%**	**58%**	**.24**
Work-study or job to pay for your college education	49%	46%	56%	.19	55%	48%	.12	53%	49%	.08
Conducted research with a faculty member	32%	**28%**	**40%**	**.25**	31%	32%	.02	**23%**	**33%**	**.21**
Participated in study abroad	15%	**12%**	**22%**	**.30**	14%	15%	.03	**8%**	**16%**	**.22**
Undergraduate coursework that includes …										
Interaction with students from non-engineering majors	85%	83%	90%	.19	85%	85%	.01	80%	86%	.18
Computer science	81%	83%	78%	.14	82%	81%	.01	79%	82%	.06
Designing and/or prototyping things or ideas	72%	73%	71%	.03	71%	73%	.02	70%	73%	.06
Art, dance, music, theater, or creative writing	55%	54%	58%	.09	59%	55%	.08	55%	55%	.01
Theory of design	55%	57%	50%	.14	54%	55%	.02	58%	55%	.06
Leadership topics	47%	46%	50%	.09	49%	47%	.03	45%	48%	.05
Business or entrepreneurship topics	35%	36%	34%	.05	34%	35%	.02	34%	35%	.02
Undergraduate extra-curricular activities										
Attended a career related event (college career fair)	75%	**72%**	**83%**	**.24**	71%	76%	.12	69%	77%	.18
Participated in student clubs or groups in engineering	45%	**40%**	**56%**	**.33**	47%	44%	.05	42%	45%	.07
Participated in student clubs outside of engineering	44%	**39%**	**55%**	**.33**	38%	45%	.14	**35%**	**46%**	**.22**
Attended a presentation about entrepreneurship	40%	38%	45%	.16	42%	40%	.04	35%	41%	.11
Attended a presentation on new engineering technology	36%	34%	39%	.09	31%	36%	.11	29%	37%	.16
Led a student organization	28%	**24%**	**37%**	**.30**	29%	28%	.02	23%	29%	.13
Participated in a community service-based club	24%	**20%**	**34%**	**.34**	26%	24%	.06	21%	25%	.10
Made use of a maker space/ prototyping lab	22%	22%	23%	.03	20%	23%	.06	18%	23%	.12
Entered a design or invention competition	13%	13%	13%	.01	12%	13%	.04	12%	14%	.04
Lived in a residential -based engineering community	13%	11%	16%	.15	14%	13%	.06	13%	13%	.00
Participated in a design club	10%	11%	8%	.10	10%	10%	.01	8%	10%	.08
Started or co-founded a student club on campus	9%	9%	9%	.02	10%	9%	.06	8%	9%	.02
Participated in a business or entrepreneurship club	8%	8%	7%	.02	6%	8%	.08	6%	8%	.07
Participated in a robotics club	6%	6%	4%	.10	6%	6%	.01	5%	6%	.06
Received funding to finance new ideas	6%	6%	6%	.02	6%	6%	.02	4%	6%	.11
Entered business plan, or elevator pitch competition	5%	5%	6%	.03	6%	5%	.02	5%	5%	.03
Started for-profit or non-profit organization	3%	3%	2%	.09	2%	3%	.03	2%	3%	.06
Attended a start-up boot camp	2%	3%	2%	.06	2%	2%	.01	2%	3%	.06
Entered a social entrepreneurship competition	2%	2%	3%	.03	2%	2%	.01	2%	2%	.03
Lived in entrepreneurship/innovation community	2%	2%	2%	.02	1%	2%	.04	1%	2%	.04
Activity Count (out of 39 activities)	12.1	**11.8**	**12.9**	**.22**	11.9	12.2	.06	**11.1**	**12.3**	**.27**
Demographics (inputs and background) and self-efficacy										
Gender (1 = Male, 0 = Female)	70%	100%	100%	NA	66%	71%	.11	74%	70%	.10
Under Represented Minority (URM) (1 Yes, 0 No)	14%	13%	16%	.08	100%	0%	NA	**25%**	**12%**	**.40**
First Generation College (1 = Yes, 0 = No)	16%	17%	14%	.08	**29%**	**14%**	**.43**	100%	0%	NA
Age at Survey - (Years)	22.26	**22.55**	**21.58**	**.26**	22.79	22.17	.17	**23.57**	**22.01**	**.42**
Family Income (0 = Low Income, 4 = High Income)	2.04	2.01	2.11	.11	**1.56**	**2.12**	**.61**	**1.30**	**2.18**	**.99**
Grade Point Average (0 = 1.8 or less, 7 = 3.8 - 4.0+)	5.14	5.12	5.21	.07	**4.61**	**5.23**	**.48**	**4.75**	**5.22**	**.36**
Carnegie Classification (R1 = 1, Not R1 = 0)	75%	74%	77%	.07	81%	74%	.16	70%	76%	.14
Engineering School Size (>2K = 1, < 2K = 0)	66%	65%	67%	.04	60%	67%	.14	**57%**	**68%**	**.21**
Engineering Task Self-Efficacy	2.42	**2.53**	**2.17**	**.44**	2.36	2.43	.09	2.37	2.43	0.07
Innovation Self-Efficacy	2.62	2.65	2.55	.14	2.64	2.62	.04	2.59	2.63	0.05

EMS 1.0 unweighted data collected in February-May, 2015
Participation Rate measured as 1 – *Yes, I participated*, 0 – *No, I did not participate*, converted to a percent (see Footnote 3)
d – Cohen's *d* mean difference effect size (**Bold** difference: > .20 small difference, > .50 medium difference, > .80 large difference)
[shaded] – variables that are the most significant contributors to Engineering Task Self-Efficacy (see Table 5)

Regarding **general co-curricular activities**, women and men report being comparably involved in *internships/co-ops* at (54% and 60%), whereas URM and FGC students are significantly less involved (41% and 46%) than are their non-URM and continuing generation peers, respectively (consistent with findings in Barry et al. 2011 and Barry et al. 2016). Women report more involvement in *conducting research with faculty* (40% vs. 28% for men) and participating in *study abroad programs* (22% vs. 12% for men).

As far as involvement in **other co- and extra-curricular activities** included in this study, women are more involved in a greater number of activities than men (12.9 vs. 11.8 activities, Cohen's *d* = .22), whereas FGC students are less involved (11.1 activities) than are continuing generation students (12.3 activities, Cohen's *d* = .27). Activities that more women than men are involved with include *attending a career related event* (83% vs .72%), *participating in student clubs or groups in engineering* (56% vs. 40%), and *outside of engineering* (55% vs. 39%), *leading a student organization* (37% vs. 24%) and *participating in community service-based club* (34% vs. 20%). A less common activity by all students is making use of a *maker space/prototyping lab* (22%) and entering a *design or invention competition* (13%).

5.2 ETSE and ISE

The dependent variables of engineering task self-efficacy (ETSE) and innovation self-efficacy (ISE.5) showed no difference among groups, with one exception, as shown in Table 3. Women had a significantly lower ETSE mean score than did men (2.17 vs. 2.53, *d* = .44), while URM and FGC students had similar scores to their counterparts.

Prior research on gender differences in engineering task self-efficacy has shown mixed results (Marra et al. 2009). Similar to the results in the current study, Vogt, Hocevar, and Hagedorn (2007) found significant differences between male and female engineering students in terms of self-efficacy. However, Lent et al. (2005) found no difference in engineering task self-efficacy by gender (both studies drew from samples at multiple sites). Self-efficacy is both context- and task-specific, and much of the self-efficacy research does not account for widely held, culturally based gender status beliefs about who is more proficient at certain tasks, regardless of actual aptitude.

Table 3 – Comparative means and standard deviations for the engineering task self-efficacy (ETSE) and innovation self-efficacy (ISE.5) scales

		ETSE				ISE.5			
Sample	n	$\bar{x}$	σ	Δ	*d*	$\bar{x}$	σ	Δ	*d*
Total	5,819	2.42	.84	--	--	2.62	.74	--	--
Females	1,722	2.17	.83	**-.36**	**.44**	2.55	.74	.10	.14
Males	4,097	2.53	.82			2.65	.73		
URM	807	2.36	.90	-.07	.09	2.64	.79	.02	.04
Non-URM	5,012	2.43	.83			2.62	.73		
FGC	932	2.37	.88	-.06	.07	2.59	.78	-.04	.05
Non-FGC	4,887	2.43	.83			2.63	.73		

d = Cohen's d mean difference effect size
Bold difference > .20 small difference, > .50 medium difference, > .80 large difference

Given the goals of the EMS project, it is notable that women and men have comparable innovation self-efficacy mean scores. The correlation between ETSE and ISE.5 is both strong and significant (Pearson $r = .71$, p <.000), hinting that efforts to increase innovation self-efficacy might have a positive impact on engineering task self-efficacy for both women and men. This could be a fruitful topic for future research.

Research Question 2 (RQ2): How do these experiences predict students' self-reported engineering task self-efficacy and innovation self-efficacy?

5.3 Regressing Activities and Learning Experiences against ETSE and ISE

Summary results from multiple linear regression analysis of all 47 independent variables (39 activities and 8 person input/background characteristics) are shown in Table 4. The full All Items regression is shown in Appendix 1. The All Items regression resulted in a model fit (adjusted r^2) of .200 for ETSE as the dependent variable and .163 for ISE.5 as the dependent variable, suggesting that these activities may do a better job of predicting engineering task self-efficacy than innovation self-efficacy.

Table 4 - Summary results from regression models of all activity and demographic items, stepwise regression and selection of the Top 15 PPM variables

Model →	**All Items**		**Stepwise Regression**		**Top 15 PPM**	
Dependent Variable	# Variables	Adj. r^2	# Variables	Adj. r^2	# Variables	Adj. r^2
ETSE	47	.200	32	.201	15	.182
ISE.5	47	.163	33	.163	15	.149

n = 5,819

Stepwise regression modeling reduced the variables to 33 and 32, respectively, for ETSE and ISE.5 without compromising model fit. However, to get a more focused view of the relative importance of these activities, we created a third model that consists of all activities that had a PPM Index of 50 or greater (the top 50 percentile of PPM relative importance), which resulted in 15 activities for ETSE and ISE.5, some similar and some different. The results of the Top 15 PPM activities, grouped into Bandura's categories of Sources of Self-Efficacy are shown in Table 5.

Dependent Variable - ETSE: Not surprisingly, of the 14 activities (and one demographic variable) that best predict engineering task self-efficacy, 8 activities fall into the Engineering Mastery category. These engineering mastery activities include high participation activities such as *Undergraduate coursework: Computer science* and *Undergraduate coursework: Designing and/or prototyping things or ideas*, and some relatively low participation areas such as *Made use of a maker space/ prototyping lab* and *High School: Learned computer programming.* One implication of these findings is that emphasizing more computer programming experiences in high school (for men and women) may be an important precursor to the development of engineering task self-efficacy. The trade-off with this approach is that for some students, encouraging more classes like computer programming may mean less involvement in other activities such as art, music, dance and theater, which could be a source of innovation self-efficacy later in their academic or professional career (but is not represented in the Top 15 PPM).

It appears that Vicarious Engineering Experiences are also important to building engineering task self-efficacy with an additional four activities falling into this category. These activities engage Bandura's suggestion that vicarious sources of efficacy include seeking "proficient models who possess the competencies to which they aspire" (Bandura 1995, p. 4), and include *Undergraduate coursework: Leadership topics* and *Undergraduate coursework: Business or entrepreneurship topics*. This, in combination with *Attended a presentation about entrepreneurship* as an undergraduate, suggests that students are looking toward future application of their engineering task self-efficacy in the workplace.

There is also a social aspect to building engineering task self-efficacy by engaging in engineering activities with a social interaction component. The activities of *High School: Participated in a robotics competition* and *Undergraduate: Entered a design or invention competition* have relatively low participation rates but may play a significant role in engineering task self-efficacy. These types of activities, such as FIRST Robotics (2017) or RoboCup Junior (Eguchi 2016) competitions in high school, have been proven to build both nascent engineering skills and socialization/teamwork skills, which conceivably form a base of experience for engineering task self-efficacy to grow.

Table 5 - Regression Analysis Summary for the Top 15 PPM Activity and Experience Variables Predicting Engineering Task (ETSE) and Innovation Self-Efficacy (ISE.5)

Predictor Variable →		ETSE				ISE.5			
Activity		*β*	SE	*t*	*p*	*β*	SE	*t*	*p*
Engineering Mastery Experiences	%P								
UG: Coursework: Designing and/or prototyping things or ideas	72%	.11	.01	8.41	.00	.05	.01	3.92	.00
UG: Worked in a professional engineering environment	56%	.10	.01	7.89	.00	.08	.01	6.77	.00
UG: Coursework: Theory of design	55%	.09	.01	6.40	.00	.06	.01	4.42	.00
UG: Made use of maker space/ prototyping lab	22%	.08	.01	6.24	.00	.04	.01	3.41	.00
UG: Conducted research with a faculty member	**32%**	.07	.01	5.43	.00	.07	.01	5.66	.00
UG: Coursework: Computer science	81%	.06	.01	5.35	.00				
HS: Learned computer programming	**31%**	.05	.01	4.42	.00				
HS: Took a shop class or engineering class	**47%**	.05	.01	4.18	.00				
Vicarious Engineering Experiences									
UG: Coursework: Leadership topics	47%	.06	.01	4.72	.00	.11	.01	8.52	.00
UG: Coursework: Business or eship topics	35%	.05	.01	3.54	.00	.06	.01	4.74	.00
UG: Attended a presentation about entrepreneurship	40%	.04	.01	3.15	.00	.08	.01	6.15	.00
UG: Attended a presentation on a new engineering technology	36%	.03	.01	2.57	.01	.05	.01	3.38	.00
HS: Learned about entrepreneurship	**24%**					.06	.01	5.09	.00
Social Persuasion Supporting Engineering Self-Efficacy									
UG: Entered a design or invention competition	13%	.07	.01	5.25	.00				
HS: Participated in a robotics competition	11%	.06	.01	4.85	.00				
UG: Started or co-founded a student club on campus	9%					.05	.01	4.07	.00
HS: Started a club, organization, or company	16%					.04	.01	3.37	.00
UG: Led a student organization	**28%**					.04	.01	2.75	.01
Positive Physiological and Emotional States									
UG: Coursework: Interaction with students from non-engineering majors	85%					.06	.01	5.07	.00
Demographics (Inputs and Background)									
Gender (1 = Male, 0 = Female)		.19	.01	15.30	.00	.09	.01	7.04	.00
Adjusted r^2		**.182**				**.149**			

n = 5,819, all data centered and standardized; % P - % participation from Table 2.
Bold in %P column indicates a statistically significant difference between women and men
- Top 15 PPM variables for ETSE; - variables added to Top 15 for ISE.5
UG: Undergraduate activity HS: High school activity

Dependent Variable – ISE.5: The overall model fit for the All Items is significantly lower for ISE.5 than for ETSE (adjusted r^2 = .163 vs .200 for ETSE, see Table 4). In the Top 15 PPM variables, some variables remained the same as for ETSE, while some variables were dropped and other variables added (see Table 5). As with ETSE, among the largest number of variables predicting ISE.5 were from the Mastery Experiences category (5 of the 14 activity variables), such as *Undergraduate: Worked in a professional engineering environment* and *Undergraduate*: *Conducted research with a faculty member*. Several new variables made their way into the Top 15 PPM variables for predicting innovation self-efficacy, such as *High School: Learned about entrepreneurship, Undergraduate: Started or co-founded a student club on campus* and *Undergraduate: Led a student organization.* It appears that experiences important to predicting ISE.5 include activities that (1) were outside of core engineering mastery experiences, (2) tended to be social in nature and/or (3) involved business or commerce learning and leadership. Leadership coursework in college was more important in predicting ISE.5 than ETSE.

Role of Gender: Gender, measured as a binary variable (male/female), was a significant predictor of both ETSE and ISE.5, with being male a strong predictor of engineering task self-efficacy ($\beta = .19$, PPM = 100, see Appendix 1). This finding is consistent with other studies indicating that men score higher on self-reported efficacy or confidence scales than do women (regardless of actual aptitude/performance--see Correll 2001). This is not to suggest self-report efficacy measures are flawed, it is more of a caution against over interpretation of these results; the Limitations section will discuss this more fully.

Model Fit by Gender, URM and FGC: The Top 15 PPM activities remain good predictors of ETSE and ISE.5 by gender, underrepresented minority status (URM) and first generation college (FGC) student status. When the gender variable is removed from the model, ETSE and ISE model fit is better for women ($r^2 = .159$ and .157, respectively) than for their male counterparts ($r^2 = .148$ and .142, respectively, m:w difference is significant at $p <. 05$). Model fit for ETSE among URM students ($r^2 = .189$) is also better than for non-URM students ($r^2 = .180$) (difference is significant at $p<.05$). There were no statistical differences in ETSE or ISE model fit for first generation college students and their continuing generation peers.

5.4 Limitations

This research uses a self-efficacy measurement as the dependent variable and this has several inherent limitations. As Bandura (2006) counsels, to be effective, self-efficacy scales must "be tailored to activity domains and assess the multifaceted ways in which efficacy beliefs operate within the selected activity domain" (p. 310). The engineering task self-efficacy measure (ETSE) attempts to measure some breadth of "engineeringness" with five items, making this a limited view. The innovation self-efficacy measure (ISE) is drawn from the "activity domain" of innovative entrepreneurship with distinct links to commerce. There are many other domains and areas of expertise that link to innovation, such as creativity, design thinking, or problem solving, to explore in future research.

This same logic also can be applied to the list of experiences and activities used to predict engineering task and innovation self-efficacy in this research. There are literally hundreds of potential learning experiences and activities that could define a high school and undergraduate learning experience and this research includes a small subset. The experiences in this research tend to focus on entrepreneurial activities by design, and perhaps to the exclusion of other activities that may be more predictive of both engineering task and innovation self-efficacy. Therefore, for future research, it may be important to broaden the scope of activities and experiences to draw broader conclusions from these data.

6.0 Conclusion and Implications

The activities and learning experiences reported by engineering students had both expected and unexpected results. As expected, a significant number of engineering students participated in activities that are associated with engineering education, such as *taking a shop class or engineering class* in high school (47%), *taking a computer science* (81%) or *design/prototyping* (72%) class as an undergraduate, *working in an engineering environment as an intern* (56%), or *attending a career related event* in college (75%). Somewhat surprisingly, given the rigors of an engineering curriculum, a significant number of students had participated in an *art, dance, music, theater, or creative writing class* (55%), *taken a class on leadership topics* (47%), and/or *participated in student clubs outside of engineering* (44%) as an undergraduate. This seems to indicate that many students are finding a way to broaden their engineering academic experience beyond expected engineering activities.

There are some important differences in participation rates by gender, particularly early in the academic career, with men being more likely to have *taken a shop class*, *learned computer programing* or *learned about entrepreneurship* in high school. These participation differences swing toward women in the undergraduate portion of their academic career, with women more likely to have *conducted research with a faculty member, participated in study abroad, participated in student clubs or groups in engineering* and *outside of engineering*, *led a student organization* or *participated in a community service-based club*.

In terms of this collection of academic and life experiences, overall prediction of engineering task self-efficacy and innovation self-efficacy was relatively low, with a model fit of these experiences predicting ETSE at (adjusted r^2 of) .200 and .163 for ISE.5. Certain patterns did emerge when the activities and experiences were sorted by Bandura's Sources of Self-Efficacy. For ETSE, the higher participation in engineering mastery and vicarious engineering experiences, the higher the engineering task self-efficacy rating. Consistent with the study's theoretical framework, this suggests that for those students who tend to focus on engineering experiences, such a focus could lead to greater engineering task self-efficacy. However, these data are cross-sectional; inferences about causality are necessarily cautious and require follow-up work that takes into account both self-selection and change over time.

For innovation self-efficacy, a broader range of experiences beyond engineering experiences was important. There was a strong foundation of engineering mastery experiences in the ISE.5 model, which suggests that the basis for innovation exists within the core engineering curriculum. However, broadening experiences beyond engineering, particularly leadership experiences that come from activities like *started or co-founded a student club on campus*, *started a club, organization, or company* in high school or *led a student organization* in college, tend towards greater levels of innovation self-efficacy. Therefore, the challenge for the engineering educator who seeks to encourage innovation self-efficacy among students is to find a way to involve broadening experiences and leadership experiences without compromising engineering content within a fully-loaded engineering curriculum.

These results provide a foundation for future longitudinal work probing specific types of learning experiences that shape engineering students' innovation goals. They also set the stage for comparative models of students' goals around highly technical engineering work. These parallel models will allow us to understand more deeply how "innovation" and "engineering" come together in the engineering student experience.

7.0 Acknowledgements

The EMS study was conducted with support from the National Center for Engineering Pathways to Innovation (Epicenter), a center funded by the National Science Foundation (grant number DUE-1125457) and directed by Stanford University and VentureWell, formerly the National Collegiate Inventors and Innovators Alliance (NCIIA). The EMS research continues with funding support from the National Science Foundation (grant number 1636442).

References

Allison, Paul D. 2009. "Chapter 4: Missing Data." In *The SAGE Handbook of Quantitative Methods in Psychology*, edited by Roger E. Millsap and Alberto Maydeu-Olivares, 72–90. Thousand Oaks, CA: Sage Publications.

Auclair, R., P. Belanger, P. Doray, M. Gallien, A. Groleau, L. Mason, and P. Mercier. 2008. *Transitions: Research Paper 2 - First-Generation Students: A Promising Concept*. Number 39. Montreal, QC, Canada: The Canada Millennium Scholarship Foundation.

Bandura, Albert. 1995. "Exercise of Personal and Collective Efficacy in Changing Societies." In *Self-Efficacy in Changing Societies*, edited by Albert Bandura, 1–45. New York, NY: Cambridge University Press.

Bring, Johan. 1996. "A Geometric Approach to Compare Variables in a Regression Model." *The American Statistician* 50 (1): 57–62.

Brunhaver, Samantha, Shannon Gilmartin, Helen L. Chen, and Sheri Sheppard. 2012. "Factors Associated with the Current Occupations of Early Career Engineering Graduates." In *Association for the Study of Higher Education Conference*. Las Vegas, NV.

Brunhaver, Samantha R., Shannon K. Gilmartin, Helen L. Chen, Michelle Marie Grau, and Sheri Sheppard. 2013. "Not All the Same: A Look at Early Career Engineers Employed in Different Sub-Occupations." In *American Society for Engineering Education Annual Conference*. Atlanta, GA.

Buuren, Stef van, and Karin Groothuis-Oudshoorn. 2011. "Mice: Multivariate Imputation by Chained Equations in R." *Journal of Statistical Software* 45 (3): 1–67.

Cao, Emily, Shannon K. Gilmartin, Qu Jin, Carolin C. Dungs, and Sheri D. Sheppard. 2016. "Business Program Participation and Engineering Innovation: An Exploration of Engineering Students' Minors, Certificates, and Concentrations." In *American Society for Engineering Education Annual Conference*. New Orleans, LA.

Choy, S. 2001. "Students Whose Parents Did Not Go to College: Postsecondary Access, Persistence, and Attainment. Findings from the Condition of Education, 2001." *Condition of Education - US Department of Education*, December.

Cooper, Harris, Larry V. Hedges, and Jeffrey C. Valentine. 2009. *The Handbook of Research Synthesis and Meta-Analysis*. Russell Sage Foundation.

Correll, Shelley J. 2001. "Gender and the Career Choice Process: The Role of Biased Self-Assessments." *American Journal of Sociology* 106 (6): 1691–1730.

Dungs, Carolin C. 2016. "Design Thinking and (Extra) Curricular Activities: A Way to Foster Student's Innovation Self-Efficacy and Career Goals in Entrepreneurship and Innovation (Master's Thesis)." Munich, Germany: Technical University of Munich.

Dyer, Jeffrey H., Hal B. Gregersen, and Clayton M. Christensen. 2008. "Entrepreneur Behaviors, Opportunity Recognition, and the Origins of Innovative Ventures." *Strategic Entrepreneurship Journal* 2 (4): 317–38.

Dyer, Jeffrey H., Hal Gregersen, and Clayton M. Christensen. 2011. *The Innovator's DNA: Mastering the Five Skills of Disruptive Innovators*. 1st ed. Harvard Business Review Press.

Eguchi, Amy. 2016. "RoboCupJunior for Promoting Stem Education, 21st Century Skills, and Technological Advancement Through Robotics Competition." *Robotics and Autonomous Systems* 75: 692–699.

"Epicenter: About Epicenter." 2013. http://epicenter.stanford.edu/page/about.

"Epicenter: University Innovation Fellows." 2017. January. http://epicenter.stanford.edu/page/university-innovation-fellows.
Ferguson, Daniel M., and Matthew W. Ohland. 2012. "What Is Engineering Innovativeness?" *International Journal of Engineering Education* 28 (2): 253–62.
"FIRST | For Inspiration and Recognition of Science and Technology." 2017. January. http://www.firstinspires.org/.
Fouad, Nayda, and Romila Singh. 2011. "Stemming the Tide: Why Women Leave Engineering." *University of Wisconsin-Milwaukee, Final Report from NSF Award* 82–7553.
Gerber, Elizabeth, Caitlin K. Martin, Elizabeth Kramer, Jennie Braunstein, and Adam R. Carberry. 2012. "Developing an Innovation Self-Efficacy Survey." In *Frontiers in Education Conference*. Seattle, WA.
Gilmartin, Shannon K., Helen L. Chen, Mark F. Schar, Qu Jin, George Toye, Angela M. Harris, Emily Cao, Emanuel Costache, Maximillian Reithmann, and Sheri D. Sheppard. 2017. "Designing a Longitudinal Study of Engineering Students' Innovation and Engineering Interests and Plans: The Engineering Majors Survey Project. EMS 1.0 and 2.0 Technical Report." Technical Report. Stanford, CA: Stanford University Designing Education Lab.
Krathwohl, D. R. 2009. *Methods of Educational and Social Science Research: The Logic of Methods*. 3rd ed. Waveland Press.
Lent, R. W., and S. D. Brown. 2006. "On Conceptualizing and Assessing Social Cognitive Constructs in Career Research: A Measurement Guide." *Journal of Career Assessment* 14 (1): 12–35.
Lent, R. W., S. D. Brown, and G. Hackett. 1994. "Toward a Unifying Social Cognitive Theory of Career and Academic Interest, Choice, and Performance." *Journal of Vocational Behavior*, 79–122.
Lent, R. W., S. D. Brown, and K. C. Larkin. 1986. "Self-Efficacy in the Prediction of Academic Performance and Perceived Career Options." *Journal of Counseling Psychology* 33 (3): 265–69.
Lent, R. W., Steven D. Brown, Hung-Bin Sheu, Janet Schmidt, Bradley R. Brenner, Clay S. Gloster, Gregory Wilkins, Linda C. Schmidt, Heather Lyons, and Dana Treistman. 2005. "Social Cognitive Predictors of Academic Interests and Goals in Engineering: Utility for Women and Students at Historically Black Universities." *Journal of Counseling Psychology* 52 (1): 84–92.
Lent, R. W., Daniel Singley, Hung-Bin Sheu, Janet A. Schmidt, and Linda C. Schmidt. 2007. "Relation of Social-Cognitive Factors to Academic Satisfaction in Engineering Students." *Journal of Career Assessment* 15 (1): 87–97.
Lichtenstein, Gary, Alexander C. McCormick, Sheri D. Sheppard, and Jini Puma. 2010. "Comparing the Undergraduate Experience of Engineers to All Other Majors: Significant Differences Are Programmatic." *Journal of Engineering Education* 99 (4): 305–317.
Manly, Catherine A., and Ryan S. Wells. 2015. "Reporting the Use of Multiple Imputation for Missing Data in Higher Education Research." *Research in Higher Education* 56 (4): 397–409.
Marra, Rose M., Kelly A. Rodgers, Demei Shen, and Barbara Bogue. 2009. "Women Engineering Students and Self-Efficacy: A Multi-Year, Multi-Institution Study of Women Engineering Student Self-Efficacy." *Journal of Engineering Education* 98 (1): 27.
Menold, Jessica, Kathryn W. Jablokow, Daniel M. Ferguson, Şenay Purzer, and Matthew W Ohland. 2016. "The Characteristics of Engineering Innovativeness: A Cognitive Mapping and Review of Instruments." *International Journal of Engineering Education* 32 (1(A)): 64–83.
Pratt, John W. 1987. "Dividing the Indivisible: Using Simple Symmetry to Partition Variance Explained." In *Proceedings of the Second International Conference in Statistics*, 245–260. Tampere, Finland: University of Tampere.

Schar, Mark F., Shannon K. Gilmartin, Elizabeth M. Rieken, Angela M. Harris, and Sheri D. Sheppard. 2017. "Innovation Self-Efficacy: A Very Brief Measure for Engineering Students." In *Entrepreneurship & Engineering Innovation Division*, 27. Columbus, OH.

Sheppard, S., S. Gilmartin, H.L. Chen, K. Donaldson, G. Lichtenstein, O. Eris, M. Lande, and G. Toye. 2010. "Exploring the Engineering Student Experience: Findings from the Academic Pathways of People Learning Engineering Survey (APPLES)." (TR-10-01). Seattle, WA: Center for the Advancement for Engineering Education.

Stanford University. 2016. "Engineering Majors Survey." *Epicenter*. October. http://epicenter.stanford.edu/page/engineering-majors-survey#About.

Toutkoushian, Robert K., Robert S. Stollberg, and Kelly A. Slaton. 2015. "Talking 'bout My Generation: Defining 'First-Generation Students' in Higher Education Research." In *Association for the Study of Higher Education - 40th Annual Conference*. Denver, CO.

UCLA: Statistical Consulting Group. 2016. "How Is Effect Size Used in Power Analysis?" http://www.ats.ucla.edu/stat/mult_pkg/faq/general/effect_size_power/effect_size_power.htm.

Vogt, Christina M., Dennis Hocevar, and Linda Serra Hagedorn. 2007. "A Social Cognitive Construct Validation: Determining Women's and Men's Success in Engineering Programs." *The Journal of Higher Education* 78 (3): 337–364.

Appendix 1

Regression Coefficients and Pratt Product Measure (PPM) of Relative Importance

Activity (Sorted by Source of Self-Efficacy and PPM Index)	Engineering Task Self-Efficacy				Innovation Self-Efficacy			
	β	r	PPM	Index	β	r	PPM	Index
Engineering Mastery Experiences								
Designing and/or prototyping things or ideas	.121	.234	.028	100	.056	.170	.009	87
Theory of design	.077	.220	.017	96	.049	.169	.008	82
Made use of a maker space/ prototyping lab	.079	.195	.015	94	.040	.158	.006	70
Worked in a professional engineering environment as an intern	.093	.156	.015	93	.085	.155	.013	97
Computer science	.063	.121	.008	68	.016	.057	.001	30
Conducted research with a faculty member	.060	.098	.006	58	.068	.123	.008	82
Take a shop class or engineering class	.045	.127	.006	58	.033	.081	.003	43
Learn computer programming	.039	.113	.004	50	-.019	.029	-.001	21
Have internship at a science, math, or engineering organization	.030	.099	.003	42	.016	.083	.001	33
Attend a science, math, or engineering related summer camp	.027	.075	.002	37	.017	.074	.001	33
Participated in student clubs or groups in engineering	.009	.042	.000	28	.011	.081	.001	30
Vicarious Engineering Experiences								
Leadership topics	.055	.148	.008	70	.109	.228	.025	100
Business or entrepreneurship topics	.035	.148	.005	54	.051	.184	.009	87
Attended a presentation on a new engineering technology	.032	.145	.005	52	.044	.173	.008	78
Done a work-study or job to pay for your college education	.029	.067	.002	36	.036	.093	.003	48
Learn about entrepreneurship	.014	.107	.001	34	.056	.143	.008	80
Attended a start-up boot camp	.009	.076	.001	30	.012	.083	.001	31
Attended a career related event (e.g., college career fair)	-.034	.035	-.001	21	-.042	.071	-.003	10
Social Persuasion supporting Engineering Self-Efficacy								
Entered a design or invention competition	.057	.150	.009	72	.025	.117	.003	45
Participate in a robotics competition	.047	.119	.006	56	.016	.068	.001	31
Started or co-founded a student club on campus	.037	.102	.004	46	.045	.132	.006	68
Start or co-found your own club, organization, or company	.028	.096	.003	41	.034	.117	.004	53
Led a student organization	.030	.088	.003	40	.046	.153	.007	74
Participated in a robotics club	.021	.094	.002	37	-.002	.044	.000	24
Participated in a business or entrepreneurship club	.007	.084	.001	29	.013	.109	.001	33
Received funding from a program to finance new ideas	.005	.091	.000	29	.016	.109	.002	36
Lived in a residential entrepreneurship or innovation community	.002	.021	.000	27	-.010	.018	.000	23
Lived in a residential or dorm-based engineering community	-.013	-.001	.000	27	-.020	.010	.000	23
Entered a business plan, or elevator pitch competition	-.002	.080	.000	26	.011	.105	.001	32
Entered a social entrepreneurship competition	-.009	.049	.000	25	.006	.072	.000	27
Participated in a design club	-.007	.093	-.001	24	-.008	.074	-.001	21
Positive Physiological and Emotional States								
Attended a presentation about entrepreneurship	.053	.140	.007	67	.089	.201	.018	100
Participated in student clubs outside of engineering	-.079	-.048	.004	46	-.035	.039	-.001	17
Interaction with students from non-engineering majors	.031	.057	.002	35	.074	.134	.010	89
Participated in study abroad	-.050	-.035	.002	35	-.024	.018	.000	22
Started your own for-profit or non-profit organization	.020	.082	.002	35	.030	.099	.003	45
Take an art, dance, music, theater, or creative writing class	-.001	-.012	.000	27	.023	.044	.001	31
Participated in a community service-based club	-.015	.015	.000	25	.020	.094	.002	37
Art, dance, music, theater, or creative writing	-.013	.030	.000	25	-.006	.052	.000	23
Demographics (Inputs and Background)								
Gender (1 = Male, 0 = Female)	.171	.197	.034	100	.078	.062	.005	60
Age at Survey (Winter-Spring 2015)	.060	.058	.003	45	.068	.033	.002	40
Institution Carnegie Classification (R1 = 1, Not R1 = 0)	-.035	-.043	.002	34	-.012	-.023	.000	26
Grade Point Average - Ordinal (0 = 1.8 or less, 7 = 3.8-4.0)	.027	.048	.001	33	-.019	.013	.000	23
First Generation College (1 = Yes, 0 = No)	-.013	-.026	.000	28	.006	-.019	.000	24
Family Income - Ordinal (0 = Low Income, 4 = High Income)	.012	.020	.000	28	.044	.049	.002	39
Under Represented Minority (URM) Status (1 = Yes, 0 = No)	-.004	-.030	.000	27	.025	.013	.000	26
Engineering School Size (>2K = 1, < 2K = 0)	.022	.003	.000	27	.019	-.004	.000	24

β = standardized beta regression coefficient for the predictor variable
r = Pearson correlation between the predictor variable and the activity variable
PPM = Pratt Product Measure ($\beta * r$)
Index = PPM fitted to a normal distribution curve (0 – 100), centered on the PPM mean
[grey shading] = Top 15 (+50 PPM) activity variables for ETSE, [green shading] - Top 15 (+50 PPM) activity variables for ISE
"Activity Count" dropped from regression analysis due to multicollinearity concerns