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Sources of Self-Efficacy in Undergraduate Engineering

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Sources of Self-Efficacy in Undergraduate Engineering

Researchers have shown that self-efficacy, the beliefs students hold about their capabilities to perform given tasks, can influence students' effort, achievement, and successful matriculation in school. Efforts have been made in the engineering community to examine self-efficacy in relationship to undergraduate engineering and persistence. Fewer efforts have focused on the types of past experiences that may have raised or lowered engineering undergraduates' efficacy beliefs in engineering. The purpose of this study is to examine the experiences that engineering undergraduate students report to have influenced their efficacy beliefs in engineering. We investigate engineering students' efficacy-relevant experiences to better understand the ways in which self-efficacy develops and the factors that students consider to be most influential to their self-efficacy. We also examine whether men and women report similar sources of self-efficacy, as has been found in related work.

Background and Theoretical Framework

In his social cognitive theory, psychologist Albert Bandura put forth a framework of human functioning that accorded a central role to individuals as determinants of the course of their own lives. This perspective countered dominant behavioristic theories, which viewed human behavior as the product of external stimuli and reinforcements. According to Bandura, the capacity to plan ahead, to reflect, and to self-regulate enables humans to exercise a large degree of control over their environments and behavior. People originate thoughts, ideas, and actions, all of which make them agents in their own lives. Central to human agency is a belief that one can bring about the outcomes one is seeking. Beliefs in one's own efficacy, therefore, act as a key determinant of motivation and action. As Bandura[1] contended, "unless people believe they can produce desired effects by their actions, they have little incentive to act" (p. 2).

Numerous research efforts have shown the power of self-efficacy to predict human behavior in a variety of domains. Throughout the academic realm, self-efficacy has been shown to influence students' achievement and their motivation to learn[2]. In the domain of engineering, self-efficacy has been shown to predict engineering students' grades[3, 4]. For example, Jones et al.[5] found that self-efficacy accounted for 35 percent of the variance in engineering students' first year GPA. Similarly, Lent et al.[6, 7] reported that students in scientific and technical programs who had high self-efficacy generally achieved higher grades than those students with low self-efficacy. Vogt et al.[8] and Vogt[9] showed that self-efficacy was more strongly related to GPA than were numerous other variables, such as academic integration, help-seeking, effort, and critical thinking.

The studies presented above describe the positive relationship between self-efficacy and academic achievement. Students with high self-efficacy tend to perform better academically than students with low self-efficacy. Researchers have also reported that mathematics and science self-efficacy are significantly related to students' persistence in engineering[10, 11]. Moreover, numerous studies have suggested that individuals' self-efficacy is related to their career-related and academic choices[12, 13]. The power of students' personal efficacy beliefs to influence students' achievement and persistence in engineering programs has now been clearly documented. However, considerably less research has focused on investigating the *development* of personal efficacy beliefs in the domain of engineering. If self-efficacy is directly related to the choice learners make to focus their post-secondary studies on engineering, what sorts of experiences build this sense of efficacy?

Sources of Self-Efficacy

Bandura[1] hypothesized that individuals form their self-efficacy by interpreting information from four primary sources. The first and theoretically most potent, *enactive experience*, refers to a person's direct experience of mastery or failure. Having successfully performed a similar task previously can boost a person's confidence in mastering similar tasks, whereas having a history of failures undermines it. A second source of efficacy information comes from seeing others' successful performances. The *vicarious experience* of observing an engineer might convince a student that she too has what it takes to become an engineer. Social models, particularly those perceived as similar to the observer, can alter a person's self-beliefs.

The third source of efficacy information comes from the evaluative appraisals of others. *Social persuasions* in the form of compliments or criticisms can raise or lower self-efficacy. For example, being told that one is "just not a math person" might shake the efficacy beliefs of a listener, leading her to forgo further math coursework and from anything that might be perceived to require math. The fourth key source of efficacy information comes from one's physiological or affective arousal when engaged in or contemplating an activity. Extreme stress or agitation might be perceived as an indication that one does not have what it takes to succeed. Satisfaction and excitement when engaged with engineering-related problems might alternatively be interpreted as signs of one's capabilities.

These four sources of self-efficacy are commonly interrelated. A masterful experience is usually accompanied by the praise of others and positive emotions. Individuals may give more weight to relevant information from one source of self-efficacy, or they may consider the interrelatedness of information from multiple sources when judging what they can do[1].

Researchers have begun to examine in greater depth the manner in which people process information from the sources of self-efficacy, primarily in the domains of mathematics, science, and writing[14]. Relatively less research has investigated the sources of self-efficacy reported by undergraduate engineering students. Below we briefly summarize these empirical findings as they relate to each of the four sources in the area of engineering. We also mention gender differences that have been reported in the literature.

Many investigations have shown that mastery experience is the most influential source of self-efficacy[14, 15, 16]. This is consistent with Bandura's[1, 17] contention that mastery experience is the most influential source of self-efficacy. Mastery experiences are particularly powerful because they provide direct evidence of one's abilities. For example, Zeldin et al.[18] found that ongoing achievements and successes enhanced men's self-efficacy in mathematics, science, and technology.

Vicarious experience has also been found to undergird undergraduate students' engineering self-efficacy. Interviews with second-year university students revealed that watching others of similar ability succeed at engineering-related tasks was a boon to students' own engineering self-efficacy[15]. Nauta, Epperson, and Kahn[19] found that exposure to positive role models was a significant factor related to the self-efficacy of undergraduate women in mathematics, science, and engineering. Women who had been influenced positively by role models were also more likely to believe that mathematics, science, and engineering careers are compatible with familial responsibilities. Women have reported being more frequently influenced by vicarious experiences than have men[20, 21].

Some research has examined the effects of verbal persuasion on the self-efficacy of engineering students. Some evidence suggests that social messages affect women more than men. Women who pursued careers in mathematics, sciences, and technology consistently reported that the messages sent to them about capabilities in these male-dominated fields served as crucial sources of their self-efficacy[21], a finding echoed in interviews conducted by Hutchison et al.[15] with second-year engineering students. Other researchers have shown more generally that being encouraged by peers and faculty makes students more likely to put forth effort and persevere in their majors[4, 11, 15].

Fewer studies have focused on examining the influential role of emotional and physiological states on the students' sense of efficacy in engineering. Hutchison et al.[20] found that students who begin to worry at the start of problem solving tasks began to think they could not complete the task. Anxiety, stress, arousal, and mood states serve as cues for imminent failure or success[1].

Although the sources of self-efficacy have been included in some studies of engineering self-efficacy, a number of limitations in this line of research should be noted. First, researchers have explored the sources of self-efficacy in a specific engineering course through semi-structured interviews. The interview process is directed by the interviewer, and the interviewee awaits the questions to be asked. The quality of responses relies on how the researcher conducts the interview. Students may not share much of their experiences if they are not at ease with the interviewer. An open-ended, structured response approach in a survey format may allow participants to have a greater sense of control of what they share and enable them to answer the questions at their own pace and in private. This format is also a more convenient way to collect qualitative data from a large sample. Second, not all four sources of self-efficacy have always been simultaneously examined. Moreover, current studies have not accurately described the specific experiences that lead to the formation of self-efficacy, particularly in the field of engineering. According to Bandura[1], people have to weigh and integrate efficacy information from the four sources. Inviting respondents to recall sources of self-efficacy freely and then probing them to recall sources particular to each hypothesized source might render a fuller picture of the factors related to self-efficacy simultaneously.

Purpose of the Study

The objective of this research was to investigate how students describe and recall experiences related to their engineering self-efficacy. Although our hypothesis was that these experiences could generally be classified according to the four sources of self-efficacy theorized by Bandura[1], we held no expectation for which specific types of experiences within each category would emerge. We also invited students to describe sources of self-efficacy that may not have mapped onto these four sources. A qualitative analytic approach was used to examine students' responses to open-ended questions about their efficacy-relevant experiences. This approach enabled us to ascertain whether students in engineering rely more on certain types of experiences than others when forming their sense of efficacy. We also sought to examine whether the efficacy-relevant experiences described by men and women differed in frequency or content.

Method

Participants

Participants in the study were undergraduate engineering students (*N* = 365) from two research-intensive universities in the southeastern United States. Students completed an online survey designed to assess their beliefs about and experiences related to engineering during the fall 2012 ($n_{\text{University 1}} = 81$, $n_{\text{University 2}} = 64$) and spring 2013 ($n_{\text{University 1}} = 186$, $n_{\text{University 2}} = 34$). Informed consent procedures were followed according to guidelines by each university's institutional review board. Table 1 shows the gender and academic level distributions for students who participated in the study.

Table 1

Participants' Gender and Undergraduate Level

	Fall 2012		Spring 2013	
	n	%	*n*	%
Gender				
Male	91	62.76	168	76.36
Female	54	37.24	52	23.64
Undergraduate Level				
Lowerclassmen	93	64.14	87	39.55
Upperclassmen	52	35.86	134	60.91

Data Sources

Participants completed a computerized survey about their motivation and beliefs about engineering. The survey included five open-ended questions and one open-selection question across three screens (i.e., survey pages) aimed at identifying events that affected students' engineering self-efficacy. The more familiar term "confidence" was used on the survey in lieu of the more technical term "self-efficacy" in keeping with the recommendations of researchers who have studied self-efficacy with adolescents[22]. Questions were phrased in broad language to encourage students to describe any event that might have altered their self-efficacy. No limit was imposed on students' responses to any of the open-ended questions.

The most general questions about students' efficacy-relevant experience appeared on the first screen. Question 1 invited students to describe any experiences that may have raised or lowered their self-efficacy: "What events have affected your confidence in your engineering skills? How did the event(s) affect your confidence?" Question 2 targeted a specific efficacy-boosting event:

“Can you think of a specific event that made you feel more confident in your engineering capabilities? Please describe.” The aim of this question was to assess a particularly salient event that raised the respondent’s self-efficacy.

On the next screen, students were presented with two related questions (Questions 3 & 4) focused on their exposure to social models and/or experiences specific to engineering. Students were asked to indicate (i.e., “check all that apply”) the ways by which they had been exposed to engineers in their life. Options included having a parent, relative, and/or friend who is an engineer; participating in a cooperative education program (co-op); working in an engineering facility; shadowing an engineer; reading an article about an engineer; and watching an engineer on television. An “other” category was available with a write-in response option. Students were then asked the open-ended question: “Of the ways you have been exposed to engineers in your life, which one has been most influential to you?”

On the final page, students were asked Question 5: “Has anyone encouraged or inspired you to be an engineer? If so, who? How did they encourage or inspire you?” This question targeted both vicarious experience and social persuasions. Question 6 was crafted to assess students’ physiological and affective state while engaged in engineering activities: “Please describe how you typically feel when doing engineering work.”

Analyses

Participants’ responses to all questions were imported into Microsoft Excel. A team of three researchers coded responses to all the questions using a start list of four codes corresponding to the four theorized sources of self-efficacy—mastery experience, vicarious experience, social persuasion, and physiological states. Complex responses that reflected more than one source of self-efficacy received more than one code. A code of *Other* was used to classify responses that did not correspond to one of these four categories. Data were then cross-checked by two researchers to ensure inter-rater reliability above .90, as recommended by Miles and Huberman[23].

The researchers generated a list of 20 second-level codes to classify diverse experiences students described related to each major source of self-efficacy (see Table 2 for a final list of codes). For example, second-level codes helped refine responses with the first-level code *social persuasions* by reflecting the different people from whom students received persuasive messages (e.g., family, teachers, peers, employers). Responses too general to receive a second-level classification retained their initial first-level code. This coding scheme was similar to that used by Usher[24] and was adapted for the context of engineering.

To check for coding consistency among raters, a random selection of 100 participants’ responses to all open-ended questions was chosen. The codes assigned by each researcher to the selected data were cross-checked by the researchers to determine the level of inter-coder agreement. Four of the selected participants provided no response to any of the open-ended questions, leaving the final number of respondents compared as 96. Inter-coder reliability was calculated by obtaining the ratio of the number of coding agreements to the total number of agreements plus disagreements. This permitted the research team to present, “an equivocal, common vision of

Table 2

List of Codes Used for Student Responses Referring to Sources of Engineering Self-Efficacy

Themes	Code	Coding Description
Mastery Experience (ME)	ME	Reference made to mastery experiences
	ME-C	Mastery experience from participation in co-op
	ME-I	Mastery experience from internship
	ME-R	Mastery experience from research experience
	ME-G (+/-)	Mastery experience related to performance attainments (+) or failures (-)
Vicarious Experience (VE)	VE	Reference made to vicarious experiences
	VE-1	VE from parents or family
	VE-2	VE from peers/friends/colleagues
	VE-3	VE through social comparison
	VE-4	VE as seen from examples of engineers in class, seen on media
	VE-5	VE from mentors (incl. shadowing)
Social Persuasion (SP)	SP	Reference made to social persuasion
	SP-1	SP from parents or family
	SP-2	SP from teachers or professors
	SP-3	SP from peers
	SP-4	SP from boss/supervisor
	SP-other	SP from other people not included in existing codes
Physiological and Affective States	PS	Reference made to feelings, mood, arousal
	FG	Feeling good, satisfied, relaxed, when doing engineering work
	DI	Disinterest, apathy for, boredom with engineering
	EX	Excited by engineering
	UC	Feelings of uncertainty, uneasiness, confusion
	SS	Feeling stressed, overwhelmed, nervous, worried
	CH	Feeling up to the challenge

what the codes mean" [23]. Coding definitions and discordant codes were discussed among the researchers to achieve a minimum inter-rater reliability of .90. Any disagreements were settled by discussion and referring to Bandura's[1] theoretical description of self-efficacy and its sources.

First- and second-level coding was used to summarize the data gathered from each of the five open-ended survey questions. Frequencies were calculated for students' responses to Question 3 (prior exposure to engineering). Response patterns were compared in terms of content and coding frequency. Data were then sorted by gender, and response patterns for men and women were re-examined.

Results and Discussion

Results from the six questions designed to investigate the sources of self-efficacy reported by undergraduate engineering students revealed rich experiences in each of the four categories proposed by Bandura[1]. We report results according to these four categories and highlight the diversity among students' self-reported efficacy-building experiences. Patterns in responses by men and women are then compared. Sample responses are provided in the Appendix.

Mastery Experience

The first and second open-ended questions invited participants to recall events that have affected their confidence in their engineering skills. Results from analyses of responses to these questions emphasize the salience and importance of enactive experiences in building a sense of one's capabilities (see Table 3). We found that, similar to previous research, most responses to event-related questions referred to specific direct experiences in engineering. For most students, mastery experiences were described in terms of specific performance attainments, such as earning relatively high marks on a test or an "A" in difficult classes. Students' achievements, such as obtaining "good" grades and passing engineering-related courses, boosted their beliefs in their abilities to pursue their engineering degrees.

On the other hand, perceived failures undermined a sense of efficacy. One student's comment illustrates the power of experience to lower one's self-efficacy and, consequently, one's career aspirations:

> The past three semesters, I have done poorly in my core Engineering classes. This makes me wonder if I am even cut out for this major, because it always seems like I'm struggling while my classmates are doing well or at least getting better grades than I am.

This woman's comparison of her performance relative to her peers' (a vicarious experience) further lowered her sense of efficacy. Other students attributed their sense of inefficacy to their performance failures resulting from what they perceived as unfair assessment practices (e.g., curving) or overly demanding instructors.

Aside from class-based performance, many students noted that co-operative experiences and internships raised their self-efficacy by building or reinforcing their engineering skills. One student remarked that having three internships gave him many skills that carried over to his coursework. Another student's response illustrates how overcoming a great challenge served as a powerful mastery experience:

> I was doing a Circuits assignment the other day over a concept I had been struggling with. Something in my brain finally clicked and I could do all of the problems with ease. I've had several events like these in classes which builds my confidence.

The open-ended nature of the survey question design allowed students to describe other keystone events, such as having the opportunity to teach a difficult engineering concept to younger students, engaging in research as undergraduates, or the trial and error of designing a working product.

Table 3

Coding Frequency for Responses to Question 1: "What events have affected your confidence in your engineering skills?" and Question 2: "Can you think of a specific event that made you feel more confident in your engineering capabilities? Please describe."

	Responses to Question 1			Responses to Question 2		
	Men (*n* = 259)	Women (*n* = 106)	Total (*N* = 365)	Men (*n* = 259)	Women (*n* = 106)	Total (*N* = 365)
Total *N* of Codes Assigned	249	116	365	223	77	300
Mastery Experience	169	62	231	163	52	215
Performance attainment	65	31	96	89	38	127
Performance failure	33	19	52	0	0	0
Non-specific	35	5	40	40	8	48
Internships	20	5	25	19	1	20
Co-op	11	1	12	8	4	12
Research	5	1	6	7	1	8
Social Persuasion	29	17	46	29	9	38
Teachers/professors	15	11	26	16	6	22
Peers	8	5	13	2	2	4
Parents/family	3	0	3	1	0	1
Supervisor	1	1	2	6	1	7
Other	1	1	2	4	0	4
Vicarious Experience	17	13	30	11	8	19
Social comparison	7	6	13	5	5	10
Peers/friends/colleagues	5	1	6	1	1	2
Non-specific	3	2	5	0	0	0
Parents/family	1	2	3	0	0	0
Mentors (incl. shadowing)	1	1	2	3	2	5
Examples in class/media	0	1	1	2	0	2

Vicarious Experience

Recall that Question 3 directly sought information about students' exposure to engineers throughout their lives. As Table 4 shows, over half of the engineering students in our sample had been broadly exposed to engineers through print and televised media outlets. Moreover, we were surprised to find that nearly half of these students have a family member who is an engineer (a quarter of students reported that one of their parents is an engineer). Men were more likely than women to report exposure to engineers in the television media, whereas women were more likely to have a parent who is an engineer (35% of women compared to 23% of men reported that their parent is an engineer). Although these data do not directly point to the influence of these sources on students' self-efficacy, it is likely that being exposed to engineers in one's environment has an influence on one's beliefs. Further research should investigate the types of exposure that are most influential.

Table 4

Coding Frequency for Responses to Question 3: "Which ways were you exposed to engineers in your life? (Check all that apply.)"

	Men (n = 259)	Women (n = 106)	Total (N = 365)
Watched an engineer on TV	159	49	208
Read about an engineer	143	65	208
Family member is an engineer	121	53	174
Friend is an engineer	105	32	137
Worked in engineering facility	81	28	109
Parent is an engineer	59	37	96
Shadowed an engineer	59	22	81
No exposure to engineers prior to college	43	20	63
Cooperative education	55	8	63
Other	12	7	19

To further examine this possibility, we asked students to tell us which type of prior exposure to engineers has been most influential to them. Their responses to this question are displayed in Table 5. Two thirds of respondents reported that the vicarious influence of social others (parents, peers, media, mentors) in their lives were most influential. Forty-four percent of women and 35% of men reported that parents or other close family members were most influential sources of exposure to engineering. These findings are similar to those reported by Zeldin and her colleagues[18, 21] who reported that vicarious experience was an influential source of self-efficacy for both women and men in science, technology, and mathematics careers. They suggested that the influence of family members was perhaps greater for women. This is consistent with other findings, which show that exposure to positive role models significantly predict the efficacy beliefs of undergraduate women in mathematics, science, and engineering[19]. Although experiences that led to mastery were also cited as influential, our findings unequivocally point

Table 5

Coding Frequency for Responses to Question 4: "Of the ways you have been exposed to engineers in your life, which one has been most influential to you?"

	Men (n = 259)	Women (n = 106)	Total (n = 365)
Total N of Codes Assigned	219	86	305
Vicarious Experience	145	61	206
Parents/family	76	38	114
Peers/friends/colleagues	28	8	36
Examples in class/media	23	8	31
Mentors (including shadowing)	18	7	25
Mastery Experience	59	19	78
Internships	25	10	35
Co-op	23	6	29
Non-specific	9	2	11
Research	2	1	3
Social Persuasion	1	3	4
Teachers/professors	1	1	2
Peers	0	2	2

to the positive effects of being exposed to positive role models on one's career path as an engineer.

People must often appraise their capabilities in relation to the accomplishment of others, and when they see others like them achieve in engineering, particularly family members, they can become convinced that they too have what it takes to succeed[1]. A number of responses to our open-ended questions illustrate the influence of modeling on one's self-efficacy. One student wrote that "My brother [who] is 14 years older than me became an engineer and would always show me all the fun aspects of physics and engineering." Another described the influence of the opportunity she had to shadow several engineers in their day-to-day careers: "You learn so much by watching them and getting a feel for their past experiences."

Social Persuasion

Direct messages received from others were also a salient source of self-efficacy for the engineering undergraduates we sampled. In fact, after mastery experience, more codes were assigned to events in which social messages were conveyed than other types of events. Receiving accolades from superiors can reinforce a sense of confidence in one's capabilities, as was the case for this student:

> I was asked to come up with a method of choosing the best spray-on bedliner for our company based on multiple aspects, the two most important of which were price and

durability. Once I had finished and given my written and spoken conclusion to multiple engineers on separate occasions, I received positive feedback and praise from all my superiors on a job well done.

When a masterful experience is followed by reinforcing praise, the psychological result can be a resilient sense of efficacy and motivation.

We asked students to recount whether someone had encouraged or inspired them to become an engineer. The frequency of codes assigned to their responses is listed in Table 6. The encouragement and inspiration to become an engineer most often came from significant people in students' lives. Many students expressed how parents and family members have been supportive of their choice to be an engineer. As noted above, knowing an engineer may provide particular inspiration. Students who are praised by engineers likely receive a special boost to their self-evaluations due to the high prestige and similarity of the social messenger[1]. One student seemed to heed the messages from such a highly credible source: "A friend that is an engineer has supported me and encouraged me to study engineering by reminding me that I can do the work." Messages from such individuals may have a lasting effect.

Table 6

Coding Frequency for Responses to Question 5: "Has anyone encouraged or inspired you to be an engineer? If so, who? How did they encourage or inspire you?"

	Men (*n* = 259)	Women (*n* = 106)	Total (*n* = 365)
Total *N* of Codes Assigned	234	105	339
Social Persuasion	138	73	211
Parents/family	89	49	138
Teachers/professors	26	12	38
Peers	13	10	23
Non-specific	5	1	6
Other	3	1	4
Supervisor	2	0	2
Vicarious Experience	57	12	69
Parents/family	33	7	40
Mentors (including shadowing)	9	2	11
Peers/friends/colleagues	7	2	9
Examples in class/media	8	1	9

Students also mentioned receiving positive messages from professionals, such as professors, supervisors, and mentors. Even the simple gesture of having friends ask for their help on engineering assignments boosted students' confidence in their engineering abilities.

Physiological and Affective States

When asked specifically about their feelings when doing engineering work, nearly half of the undergraduate students in our sample reported positive affect, such as feeling satisfied, relaxed, and comfortable (see Table 7). A second large proportion of responses expressed pressure, fear, and anxiety regarding engineering. Generally speaking, this finding suggests that although students may find engineering challenging, their perceived efficacy might benefit from the positive emotions they feel when engaged in their work. Gender seems to play a role in the level of emotional and physiological arousal engineering students experience. One third of the women in the sample reported stressful feelings, whereas only 23% of men's responses referred to stressors. One woman's response aptly demonstrates the link between physiological and emotional arousal and self-efficacy:

> Depending on the difficulty of the assignment and the amount of other assignments I have, I can sometimes get stressed out. But most of the time I feel fairly confident that I will be able to complete the engineering work successfully.

Remaining responses expressed—in roughly equal proportion, apathy or boredom, uncertainty or confusion, excitement, and challenge.

Table 7

Coding Frequency for Responses to Question 6: "Please describe how you typically feel when doing engineering work."

	Men (n = 259)	Women (n = 106)	Total (N = 365)
Total N of Codes Assigned	296	138	434
Good, satisfied, confident, relaxed, comfortable doing engineering work	112	43	155
Feeling under pressure, stressed, nervous, worried	55	36	91
Up for the challenge	24	6	30
Excited by engineering	20	6	26
Disinterest, apathy for, boredom with engineering	15	5	20
Feelings of uncertainty, confusion, uncomfortable	9	10	19

One of the shortcomings of quantitative research on the sources of self-efficacy has been that measures targeting physiological arousal are negatively worded and reflect adverse physiological or emotional states either primarily or exclusively[14]. Results from the open-ended questionnaire used in this study demonstrate the complexity of efficacy-relevant physiological states and feelings associated with engineering work. This might have been difficult to capture quantitatively.

What are the "optimal" feelings to have for increasing one's self-efficacy? Pajares[16] argued that work that builds students' self-efficacy should be "hard enough that it energizes, not so hard that it paralyzes" (p. 344). Participants' responses seemed consonant with this observation. As one respondent wrote, "Doing engineering is similar to lifting weights at a gym. You push yourself so hard and while you are doing it you can't believe that you are lifting as much as you are. Then when you are done, you feel accomplished and rewarded." Many students' responses seemed to agree that some degree of challenge and frustration is helpful. On the other hand, one student described the paralysis felt when engineering work is not properly scaffolded:

> [I feel] terrible, demoralized, and incredibly anxious. A homework set rarely seems to establish the basics before delving into more complicated procedures. Sometimes, I understand a problem perfectly on a conceptual level, but there is so much monotonous number crunching that it still feels like a hopeless nightmare.

Clearly, instructors should carefully consider how the work they assign might be perceived by their students. Checking in with students about their stress level might be one useful tool to help professors tailor instruction in a way that is efficacy-building.

Findings from this study complement previous research on the sources of engineering self-efficacy by expounding on diverse efficacy-relevant experiences. Students' rich descriptions of their experiences provide insight into their cognitive processing leading to the formation of their efficacy beliefs. Responses revealed that students reflect on their experiences and how these experiences influence their confidence in their engineering capabilities. Social experiences are particularly powerful. Men and women in this study generally reported similar sources of their self-efficacy despite having been exposed to engineers in different ways. The similar trends in the frequencies of responses provide some evidence that men and women similarly rely on one or more types of experiences than others when forming their sense of efficacy. These trends notwithstanding, using a statistical means of examining whether the frequency of efficacy-relevant experiences (or perceived experiences) differ for men and women would be an appropriate next step.

Results of this qualitative study on the sources of self-efficacy could help educators understand how engineering students perceive their experiences both before and during their undergraduate engineering program. These results provide further evidence that mastery experience is the most influential source of students' self-efficacy. In particular, performance attainments help boost students' confidence in their engineering capabilities. Instructors should continue to include in their courses opportunities for students to master content and develop their skills. They should also encourage students to participate in co-ops, internships, and research opportunities that provide both mastery and vicarious experiences. Exposure to engineers and what engineers do helps students to envision and realize their capabilities as future engineers. Recognizing the influence of social messages, instructors could be more mindful in providing feedback and/or comments regarding students' work and abilities. Further examination of the sources of engineering self-efficacy is recommended to understand how students' perceptions of their experiences relate to their achievement and retention in engineering programs.

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Appendix

Sample Responses Verbatim From Participants Corresponding to Bandura's[1] Four Sources of Self-Efficacy

Mastery Experience

- I hosted and did the rocket launch for AIAA. Teaching the smaller kids and having them understand me boosted my confidence in my abilities. If I can explain it to another in a way that they can understand, then I've definitely got a handle on it myself.
- My Sophomore year internship, when I was successfully able to finish 8 projects in 12 weeks. This was huge because the previous year I had struggled to finish 1.
- One specific example is when the vision tracking system that I had programmed for the rotating turret on top of our robot worked exactly as I had imagined it would, even though some of the physical design specifications, and design requirements had changed while I was working on the code.
- In Process Principles, I got a 100% on the first test and an A in the class. As a class that has been given such a bad reputation as the "weed out" class, I was proud to have conquered it.
- I successfully designed and implemented some of the circuits in my lab.
- Getting a near perfect score in thermo after feeling as though i did badly. As well as my 4.0 last semester.
- Doing undergraduate research for the university helped me realize I could do this professionally.
- Building a solar powered race car. On the solar car team, I've gone through designing something, seeing it break, and then fixing it until it works properly. Successfully designing something and fixing something that's broken has given me more confidence.

Vicarious Experience

- Throughout the first week of the co-op tour, I spent a part of each day learning a different process at the plant. At the end of the week, I felt I could draw out the entire facility from scratch, detailing each process. After seeing what all of my coworkers do on a daily basis, I gained confidence in realizing that I would be able to do what they do one day.
- Having my dad as an engineer has really helped me see what engineering is all about.
- I picked engineering because I wanted to be a MythBuster or a Disney Imagineer...so TV and Internet.
- Recently began a co-op tour, and believe that I will have no problem one day performing at the level that my coworkers perform.
- One of my professors. He maintains interest in his class and also shows a more personable side. He had told personal stories about his life; some pertaining to engineering and some not. It makes me think, that sounds pretty cool. I could see myself doing that.

Social Persuasion

- First semester freshman year in my Calculus class, most of the class failed, but I got a grade in the high 90's and my professor congratulated me. That made me think my engineering capabilities were good enough to make it through this program.
- When my mentor/advisor told me he thought I had what it takes to become an engineer, even though I was doubting myself.

- Another student asking for my help in studying for an engineering exam and then being able to help them understand the material and seeing them get a good grade from my help increased my confidence.
- My parents and friends have encouraged me to become an engineer due to my success in engineering-related subjects in school.
- I received good feedback from a professor on my engineering work and that made me feel pretty confident and as i i could do even better the next time.
- The one specific event that made me feel more confident in my engineering capabilities was the day that an engineering company saw my potential and gave me the opportunity to intern for them.

Physiological State

- I feel challenged at times, but I love the feeling of getting the correct answer on a difficult problem.
- I feel normal, though often slightly stressed due to what I perceive as a significantly larger-than-average workload. Doing the work is usually very interesting so I enjoy it, and I really enjoy when long periods of work result in a solution/final products which I achieved independent of other sources.
- I feel nervous if it's homework. But if it's something I know how to do then I obviously don't mind doing it. If it's for work and I've been trained or told how to do it then it doesn't bother me and I most likely enjoy it.
- Engineering work is challenging and can be frustrating from time to time but accomplishing that same work is very satisfying and often you learn something along the way.
- I feel good and excited when doing engineering work because I love to learn more and understand engineering in our world today. I like to know how and why things work based on my engineering knowledge.
- Slightly stressed, occasionally overwhelmed. But once I complete the work I feel accomplished and satisfied.
- I feel challenged and love figuring out what I need to do to make something work and solving the problem.
- I usually feel stressed and tense but engaged. Occasionally, there is no stress involved, but usually there is. I really enjoy the feeling of accomplishment and the challenge involved with engineering work.