AC 2012-4892: CHANGING THE FACE OF ENGINEERING: CAN PHOTOVOLTAIC ENGINEERING LEAD THE CHARGE?

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Changing the Face of Engineering: Can Photovoltaic Engineering Lead the Charge?

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Abstract

The low recruitment and high attrition rate of women in engineering is well documented. Women account for only twenty percent of the entering class cohort, and drop out at a rate ten percent higher than their male counterparts.[1] Although in the past twenty years women have made inroads into many fields that were male-dominated, women have made little or no progress in engineering.[1]

This paper has three goals. First, this paper will review existing literature that identifies current and alternative theories about why engineering programs do not retain female students. Second, this paper will synthesize motivational psychology research into a best-practice model for engineering programs. Last, we hypothesize that photovoltaic engineering programs are uniquely positioned to incorporate these recommendations.

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Changing the Face of Engineering: How Photovoltaic Engineering Can Lead the Charge

University engineering programs are well aware of the difficulties they face recruiting and retaining female students.[1] For example, women account for only twenty percent of entering classes, [2] and the women who do enter these programs are twice as likely to leave as their male cohort.[3, 4] Furthermore, although more women are generally graduating from university than men, and women have become the majority of the student body in several non-traditional disciplines, the percentage of women who graduate from engineering programs has decreased every year since 2002. [5, 2] Naturally, this under-representation of female students at the student level leads to further disparities in the representation of women at the industry and faculty levels.

The lack of women in engineering raises questions about their motivation to engage in the profession. Two of the metrics used by educational psychologists for identifying and measuring motivation are task choice and persistence. Judging by these metrics, women do not display motivation for becoming engineers. [1, 6]

This paper, presented as a literature review, summarizes the current focus of motivational researchers within the engineering education field. It also suggests other established motivational frameworks that may be more useful in understanding why women are under-represented in engineering. We will synthesize research from engineering and educational psychology to offer a best-practice solution that attempts to address the disparity of male and female representation in engineering. This best-practice guide can inform emerging disciplines and those of increasing demand, such as Photovoltaics (PV) engineering, that are uniquely positioned to learn from the existing research and incorporate practices that are more likely to attract and retain women in all areas of engineering.

Photovoltaics

The field of photovoltaics (PV) is the design, construction and implementation of solar cell arrays for the direct conversion of solar energy.[7] PV engineering is uniquely positioned to fill the growing energy demands in the marketplace. Solar energy needs are increasing – both economically and environmentally – because of the necessity for renewable energy technologies.[8] PV is a rising field in engineering, having an average growth of 40% per year over the last twenty years.[9] Among other skills, the field requires an understanding of electrical engineering, materials engineering, semiconductor physics, and sustainability.

Great strides are being taken in PV engineering to remove barriers of participation and encourage the cooperation of others in related engineering fields.[10] For example, curricular efforts are underway to enhance the interdisciplinary nature of PV, aid students in their learning of PV and increase their persistence in the field.[6] To facilitate these efforts, engineering educators are starting to identify misconceptions inherent in learning PV, enhance educational technology resources (for example, pveducation.org), and improve existing photovoltaic and solar energy courses universally.[6, 10]

Photovoltaic engineering is not intrinsically more suited to women than other engineering disciplines. However, because it is an emerging field, engineering educators have a unique opportunity to create an environment that incorporates strategies we know increase the motivation of students. As such, photovoltaic engineering has the opportunity to become an example in the engineering industry of a discipline that is able to attract and retain female students.

Current research focus: Self-efficacy and motivation

Self-efficacy is a construct frequently used to examine an individual's motivation to engage in particular tasks, including career choices.[11-13] Naturally, engineering education researchers have focused on self-efficacy to address the low motivation and high attrition rate of women in engineering programs.[14-17] As defined by Bandura, 1986, self-efficacy is the belief one has in one's capability to perform specific tasks. Unlike global self-confidence, self-efficacy is task specific and can only be inferred for the task being examined.[18] For example, an individual may have high self-efficacy for repairing a computer, yet have low self-efficacy for composing music. Generally, a person is more motivated to engage in a task for which she has high self-efficacy (i.e., thinks she can succeed).[19]

Knowing the relation of self-efficacy with motivation, engineering educators have focused intensely on it. Researchers have devised ways to measure self-efficacy in engineering students[14] and have successfully conducted interventions that have increased self-efficacy levels of female engineering students.[15] These interventions have increased self-efficacy by engaging female engineering students in mastery-orientated classes[15] and curriculum design.[20] A mastery-orientated classroom emphasizes learning new skills by focusing on the processes they involve. For example, Baker and colleagues, 2007, developed a course that embedded "tinkering" activities and applied technical skills. Class content that increased self-efficacy adhered to Bandura's social cognitive theory principles and, as such, had social relevance and real-world context, as well as stressing a mastery approach to learning.[15]

Considering the relationship between self-efficacy and motivation, it is not surprising that self-efficacy is also related to persistence.[21] Therefore, as women do not persist in engineering it would be a natural assumption that female engineering students would have lower self-efficacy than their male counterparts. That is, women feel less capable of succeeding in engineering than men. However, for researchers exploring the motivation of women in engineering, self-efficacy has provided interesting and perhaps unexpected results. Recent experiments measuring the self-efficacy of female engineering students engaged in engineering specific tasks reported that self-efficacy between genders is not significantly different.[17] For example, in a study of 429 male and 84 female students taking a mechanical and aerospace engineering course, Stump and her colleagues, 2011, found no gender difference for either performance or self-efficacy. [17]

If evidence exists that women have high self-efficacy for engineering, the question remains, why are women not choosing engineering, and when they choose it why do they not persist? The answer is not the under-performance of female engineers. In a study designed to examine the academic performance of students who drop out of engineering programs, researchers used a cross-sectional design over 26 semesters of nine engineering programs in the

United States. The study found that the reported GPAs of female students leaving engineering programs were not only of a passing grade but were also significantly higher than their male cohort's.[5] Women's motivation to persist in an engineering program was lower than their male counterparts despite a higher GPA and despite being in academically good standing with the university.

Although there is no doubt that higher self-efficacy increases motivation,[18] it may be that the self-efficacy of women in engineering programs contributes less to their attrition rate than other factors. This suggestion is supported by Chalk and her colleagues, 2005.[22] They found that although women were self-efficacious in male-gendered occupations, including engineering, they constrained their career choices along gender lines. This implies that factors beyond self-efficacy contribute to women's engagement in engineering.

It is our hypothesis that higher self-efficacy alone is not enough to understand the low recruitment and high attrition rate of women in engineering. Therefore, we should look to other motivational factors that may explain women's attrition in engineering better than self-efficacy; *identity, implicit beliefs* and *value*. Women may believe an engineering career is incongruent with their identity as a female. Women may believe that the capability to become an engineer is implicit and fixed. Additionally, training as an engineer may have little value for women because of the stereotypes about who becomes an engineer. [23, 24]

Identity and motivation

For many women, their identity as a woman and the identity as an engineer are in conflict. Research has demonstrated that engineering is stereotyped as a male occupation, rather than a female occupation. In studies where participants are asked to explicitly categorize professions by gender (done at their own time), engineers are gendered male more than female. When participants are asked to categorize professions under the pressure of time (an implicit measure), engineering is categorized even more strongly as a male occupation. [28] It is important to note the difference between implicit and explicit stereotypes – explicit stereotypes are often affected by motivation and perceived social correctness. [56] However, respondents will answer with less conscious behavior when stereotypes are measured implicitly. Such findings are problematic for engineering programs trying to motivate female students in two ways.

Firstly, research by Rosenthal, 2011, suggests that women are significantly more likely to stay in engineering programs if they consider it salient with their gender. If engineering is perceived as a male-gendered occupation, there will be gender incongruity for many women and consequently a higher attrition rate.[29]

Secondly, salience is important from a role-model perspective. Bandura, 1986, emphasized the importance of model salience for promoting behavior changes [27] and if women entering engineering find little salience with the industry and people within it, modeling is less likely to be utilized as a motivational tool for female students. Furthermore, Bussey and Bandura, 1999, emphasized the importance of perceiving models as successful – a successful model impacts behavior change more than an unsuccessful model. [27]

Unfortunately, engineering lacks an abundance of successful female role models. [1] And because research suggests that engineering is considered a male-gendered career,[22] the industry struggles to break the cyclical nature associated with having no successful female models.

The *future* identity of women should also be considered. Time traveling to a possible future is motivation to persist in the present. [30] When female undergraduate students were asked about future career possibilities, female students categorized male-gendered careers (including engineering) as idealized future possible options. That is, something they would *like* to do. However, the participants did not *expect* male-gendered careers to be future possible opportunities for them.[22] Although women may want to pursue male-gendered careers, it is likely that they are unable to see a pathway to such a career identity. This interpretation is supported by Hilpert, 2011, and his colleagues. In their study of engineering students, male students had significantly more future possible professional goals than female students. Furthermore, male students' goals extended further into the future than female students. This means that even for women in engineering programs, they perceive less professional future possible careers than their male counterparts.[30]

Implicit beliefs and motivation

The implicit beliefs students hold about their intelligence has consistently shown to predict persistence at a task in the face of difficulty and failure.[25, 26] Implicit beliefs are measures of perceived malleability or stability of intelligence. For example, individuals who believe that intelligence is innate and cannot be changed are considered to have a fixed mindset about intelligence. By contrast, individuals who believe that intelligence is something that changes over time, or with effort, are considered to have an incremental mindset. Students with a fixed mindset tend to give up on difficult tasks and shy away from challenging work (that may expose their inability to not excel immediately). Conversely, students with an incremental mindset thrive when challenged. They see setback and failure as a chance to learn and, as a result, enjoy tasks that require effort and developing new skills. [25]

Current research suggests that women's implicit beliefs about science ability may reduce their motivation. When studied, women perceive science ability significantly more as a fixed trait than their male counterparts.[31] Specifically, Heyman and colleagues, 2002, suggest that women consider engineering skills to be implicit.[32] These studies suggest that women view engineering ability with a fixed mindset – unchangeable. Students with a fixed belief about ability exert less effort, give up on challenging tasks and avoid situations that expose weaknesses. Female engineering students' fixed belief of ability may decrease their motivation when facing inevitable challenges, and contribute to the low recruitment and high attrition of female students.

Value and motivation

Expectancy-value theory was specifically developed to better understand the academic and career choices of women.[33] Expectancy-value theory predicts that people will be motivated to engage in tasks if they see value in those tasks *and* expect to succeed.[34] Expectancy can be likened to self-efficacy, the perceived capability or success one has for a task. As previously stated, engineering self-efficacy of women is similar to that of men – typically high.[35] In the expectancy-value model, the product of expectancies and values relate directly to performance, persistence, and task choice. If students value the utility of a task, and expect to succeed she will persist with it.[35]

In the expectancy-value model, expectancy and value are not additive predictors of motivation. Rather it is the interaction of expectancy and value that predict motivation. Therefore, if expectancy, or self-efficacy, is lacking, persistence is not likely to occur because of the interaction effect. [23] Therefore, both expectancy and value are necessary for motivation, and ultimate persistence with a task.[36] This may explain why self-efficacy alone is not a predictor of retention for women in engineering. Recent findings suggest that male and female engineering students have similar self-efficacy, or expectancies, about their capability. What could be lacking for female engineering students' motivation is value. If they see little value for engineering, their motivation will be low regardless of their self-efficacy.

Value can be broken down into four components; attainment value, intrinsic value, utility value, and cost value.[37] Attainment value is how much weight an individual gives the consequence of doing well at a specific task. For example, students may not have intrinsic motivation to study for exams, but they may value attaining a good result because of the satisfaction it gives them. Intrinsic value is associated with how much value is placed on the enjoyment derived from carrying out the task. This extends to positive psychological outcomes resulting from the engagement in the tasks. Finding utility value in a task is finding personal relevance and usefulness for the specific situation in both the present and future.[38] This may include recognizing the value of doing well in class even when the content has no direct use. Finally, students are motivated by the relative cost associated with carrying out the task. Cost value pertains to the price one is willing to pay in order to engage in a task – including the activities you have to give up to engage in the task, how much effort is needed, and any emotional issues engagement in the task causes.

The predictive nature of the expectancy-value model has been supported by researchers both in mathematics[39] and more recently in engineering.[40] In post-secondary engineering education, Jones and his colleagues, 2010, found that value is associated with persistence of students from an undergraduate level upwards.[40] In this study, however, they found no difference in value beliefs between men and women. Conversely, Matusovich and her colleagues, 2010, did find value differences between men and women; namely that female engineering students had lower attainment values than male engineering students.[41] This study is in line with work by Eccles, 2003, who notes that attainment value is linked to occupational choice in students, and differentiates along gender lines.[23]

The impact of value on motivation is remiss without a review of future time perspective theory (FTP). FTP adds a level of time perspective to utility value by providing a perception of time in which goals and achievements exist. [57] Of specific importance is that people with longer FTP typically have greater value orientations towards their futures.[42, 43] Therefore, finding utility for a task or action in the present may be easier when it is connected to a goal in the future.[44] Much like future possible selves, future orientations provide a catalyst for persisting with tasks that meet long term goals. Students with a FTP for becoming an engineering professional are likely to have stronger future possible "engineering" selves. As a result, they may work harder on their present coursework because they see more value in that work and realize it helps them reach their future goals.

One other value consideration for engineering educators is whether male and female engineering students value the same or different things. Eccles and her colleagues, 2007, has stated that women value fields associated with social and humanistic good, explaining why they choose careers in fields like medicine.[45] These finding replicate earlier work by Lippa, 1998, who suggests that male students are more interested in "object" type occupations and women are more interested in "people" type occupations.[46] However, recent engineering education literature has not supported these findings.[47, 48]

A best-practice model to increase the recruitment and retention of female engineering students

An engineering program designed to maximize the recruitment of female students and minimize the attrition rate should consider the effects of *identity*, *implicit beliefs*, and *value* on motivation.

Identity

Addressing the issue of gender incongruence and the effects of recruitment and retention should be a long-term project for the engineering industry. It is also of a cyclical nature; the more women in engineering the more congruence it will have with other women. Ideally this issue would be addressed at a young age when children are socialized into gendered career norms. However, engineering programs do still have the power to make an impact on the gender incongruence female students may experience as potential engineers. Efforts are being made to create outreach initiatives exposing younger girls to engineering.[51] PV is certainly not the only example but can do its part in limiting gender incongruence through the design and implementation of programs both inside and outside of the classroom.

Bandura, 1986, emphasized the importance of salient role models in changing the behavior and motivation of individuals.[18] That is, to be most effective, role models should share similarities with the mentee. If engineering departments want to encourage more women to enroll and persist in engineering programs, they should increase the number of female faculty members so female engineering students have more salient role models. One facet of PV that is unique is the interdisciplinary nature of the field. Increasing the number of women faculty in the field is more likely because there are numerous engineering fields embedded in PV. Women make up little of the engineering academy, [2] however, inclusion of the numerous engineering disciplines being integrated into PV engineering provides an opportunity to expose students to more female academics. One example of this is QESST, the Quantum Energy and Sustainable Solar Technologies Engineering Research Center that draws from material science, sustainability, educational psychology, electrical engineering, and semiconductor science. In this initiative 50% of the directors are women.[10]

Female engineers have less future possible professional career goals than male engineers, and perceive a shorter time frame in which they aim to achieve these goals. [30] To address this deficit in career goals and timeframe, engineering programs can use role models and mentoring programs. Salient role models are important for women to see that a professional career is possible, and mentors can help female engineers navigate their career paths in both the present and future. CareerWISE is an example of a university based program created to increase the motivation of female STEM students (including engineers) by providing role-models and mentors.[1] Engineering programs are encouraged to implement formal mentoring programs for female students. This may entail peer mentoring, where upper-level classmates offer support to entering students, or more structured mentoring with female engineer professionals. Because there is a lack of women working as engineering faculty, programs may have to extend their reach to the private sector in search of role-models. Female role-models working as engineers will provide female engineering students with a future professional goal and perhaps even an example of a career that extends beyond the time-frame many students imagine is possible.

Implicit Beliefs

Research suggests that women's implicit beliefs of engineering ability (mindsets) are significantly more fixed than male's beliefs. Because fixed mindsets have a negative impact on motivation and persistence, the engineering community may benefit from creating an environment that induces incremental beliefs of intelligence in all students. As demonstrated by Aronson and Steele, 1995, beliefs of ability can be successfully changed with interventions.[49] When students are exposed to an environment emphasizing that expertise is a learning process they are more likely to adopt an incremental mindset. Engineering instructors can help create this environment by referring to their own gradual development from a novice to an expert engineer and discussing engineering ability as something that grows and changes. In addition, difficulties and setbacks that students encounter should be framed in a way that suggests they are part of the learning process and emphasizing at every possible opportunity that succeeding as an engineer takes time, strategy use and effort. By contrast, if students are exposed to an environment that instills a belief that ability is a gift that students either have or do not have; they adopt a fixed mindset and their persistence is probably reduced.[50]

Value

Increasing the perceived value of class content has been successfully done in other fields and can be emulated in engineering.[52] Engineering educators can learn from the abundant research conducted in math and science that has demonstrated how value content can be increased. [52] For example, engineering educators can make the content more relevant to the students. Activities can be structured so students can see their value, and the instructor can be proactive at helping students connect the course content to the larger engineering picture. Motivation research has documented that for students to change their perception of what is valuable, they must make the personal connection of the content to the goal themselves.[53] Unlike other domains in engineering, like aeronautical engineering that few people see and interact with, PV has inherent usefulness because it is more accessible. Individuals not only see PV units installed on the roofs of homes and businesses that use solar energy, but they may also become aware of solar energy's growth and potential,[54] with over 100,000 people already employed in the PV industry.[9]

Some academic institutions are spearheading the PV movement. For example, Arizona State University (ASU) leads the country in its use of PV on the university campus by making the learning of PV relevant and useful to students. [55] Aside from ASU's large investment in PV as an energy source, it is also making investments in the education of PV engineers. Similar investments in PV education are being taken at other universities across the United States, including MIT, Caltech, and University of Delaware.[10]

Lastly, programs should emphasize the future social perspective of the content being taught in the classroom. Although this is not considered the solution to the gender problem by some in the field of engineering education, we believe it will contribute to increased retention of female students. For example, PV can be viewed as the solution for people without power in third world countries. It can save lives when major catastrophes strike leaving communities strapped for power, and it can limit pollution and greenhouse gas emissions that threaten the planet and our way of life. As suggested by Eccles and colleagues, 2007, embedding the curriculum with examples of how engineering brings about social change could encourage more women to pursue a career in engineering. [45]

Conclusion

This literature review is intended to introduce an alternative approach for increasing the motivation of women in engineering. We believe that although the self-efficacy of female engineering students is important, it is not sufficient to understand the low motivation of female engineers. In addition to self-efficacy, programs should also place emphasis on engineers' *identities*, *implicit beliefs* and the *value* engineering gives to our communities.

The research discussed in this literature review challenges engineering educators to change the face of engineering by looking at different motivational approaches when framing the attrition rate of women engineers. Although the theories discussed have not fully been explored in engineering, a large body of persuasive work exists in other fields. There is no reason to suggest that the motivation of female engineers will be an exception to the findings to date, but specific research is needed to understand how *identity, implicit beliefs* and *value* contribute to the persistence of female engineers. A preliminary research agenda should include:

1. Identity: Do women develop an identity as an engineer? What steps promote identity development that can be infused into engineering education?
2. Beliefs: What are women's implicit beliefs about engineering? How can we create useful and effective interventions to promote an incremental mindset?
3. Value: What is the value for women in engineering? How can we structure content in order to enhance women's value for engineering?

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