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The Impact of an Intensive Design Experience on Self-Efficacy, Valuation of Engineering Design, and Engineering Identity in Undergraduate Engineering Students

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Introduction

This paper reports on a NSF IUSE:RED project that is focused on integrating elements of needs finding and design into courses throughout all four years of the engineering curriculum. The project is based on the theory that providing students with increased opportunities to hone their skills in these areas in a manner that is continuous throughout their progression through an engineering program should increase their self-efficacy beliefs, valuation of engineering knowledge and skills, and the extent to which they see themselves as engineers (i.e., engineering identity). This should, in turn, increase students' engagement with curricular and extracurricular engineering related content and activities and ultimately retention, persistence, and the overall quality of learning. Toward this end faculty on this project have developed a set of teaching strategies grounded in design, problem, and project-based learning [1], [2] and have begun implementing them in selected engineering courses and a newly developed Design Fellows Program. The Design Fellows program is an intensive design experience that a small number of selected students participate in for five weeks. This paper reports on the experiences of students who participated in the Design Fellows Program in the Summer of 2019. A mixed method research design that included a validated exit survey [3], and a focus group was used to gather descriptive and interpretive information on the students' feelings of self-efficacy, valuation of engineering knowledge and skills, and engineering identities and gain a deeper understanding of how these social psychological motivators of learning are experienced by students in their coursework and everyday lives.

Background

The overall goal of the RED project at North Carolina A&T State University is to develop engineers that have a strong sense of engineering identity, increased valuation of the skills and knowledge contained within the field, and an increased belief in their ability as an engineer (i.e, self-efficacy). They will also see the value of their education and contributions as engineers. This is done through curricular changes and extracurricular activities that incorporate needs finding and engineering design activities. The overall project is grounded in Social and Psychological theories of socio-ecological processes [4]-[6], Values [7], Self-efficacy [8], and Identity [9]. These theories have been used to develop and validate an integrative exploratory model of engagement in engineering activities (see Figure 1). This model suggests that self-efficacy beliefs are the most proximal (or direct) predictor of student engagement the most proximal (or direct) predictor of student engagement in engineering activities such as study groups, summer internships, or research symposia. Engineering values and identity, however, are more distal and indirect motivators of engagement in engineering activities. This, in turn, suggests that an effective way to increase a students' engagement in engineering activities is to provide students with increased experiences designed to build their capability to actually 'do' engineering. This is the rationale grounding the RED Design Fellows program. This program aims to create students that will be able to solve relevant problems using the engineering design process.

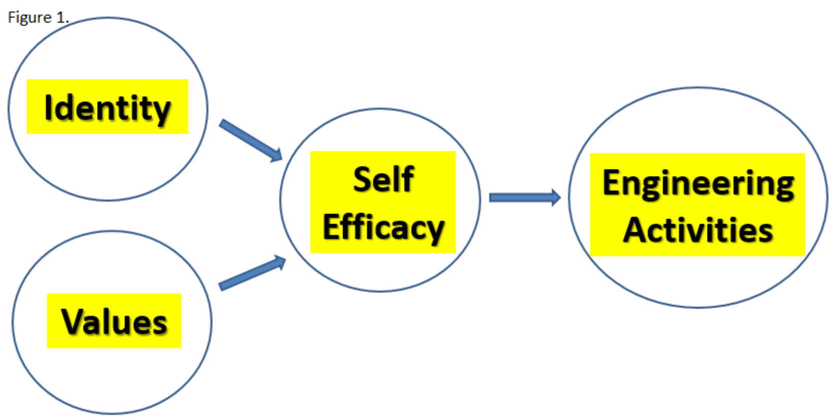

Figure 1 - Exploratory model of engagement in engineering activities

According to Accreditation Board for Engineering and Technology, Inc (ABET), engineering design "involves identifying opportunities, developing requirements, performing analysis and synthesis, generating multiple solutions, evaluating solutions against requirements, considering risks, and making trade-offs, for the purpose of obtaining a high-quality solution under the given circumstances." [10] Engineering design is a process of generating multiple creative solutions for an identified need, analyzing these solutions, and implementing the most appropriate one. Engineering design is typically taught using a series of iterative steps. The number and title of these steps may vary by the engineer or institution. However, the following broad categories are typically used [11]

1. Needs Finding and Assessment (Problem Evaluation)
2. Concept generation and evaluation
3. Analysis and selection of an appropriate design
4. Implementation of the design

Through the various engineering design experiences, participants may gain confidence in their ability as engineers (self-efficacy). They may also consider themselves part of the engineering community and appreciate the work they do in the field.

The RED Fellows program and the overall RED project are rooted in design, project, and problem-based learning techniques. Problem-based learning is an experiential process where students learn by using their experiences and other knowledge to solve relevant problems. Problem-based learning was first coined by Donald Woods of McMaster University. He and others developed a problem-focused approach for developing medical students. The techniques simulated actual patient problems. [12] Hmelo-Silver states that problem-based learning is "well suited to helping students become active learners because it situates learning in real-world problems and makes students responsible for their learning."[2] Chandrasekaran et al. describe design-based learning (DBL) as "a type of problem or project-based learning. With DBL, students gain knowledge while designing a solution for a particular need."[1] These techniques are implemented with the expectation that students will gain an appreciation for the knowledge and skills required to be an engineer as well as associate themselves with the engineering profession.

It has been reported that engineering design capstone courses have shown to increase student engineering identity, motivation, and self-efficacy. [13] Rohde et al.'s work with electrical engineering students indicate that design experiences "strongly influenced" both engineering identity and belongingness to the engineering community. [14]

Methods

The RED Design Fellows program is a 5-week program where participants receive intensive exposure to the engineering design process. They work in teams to attempt to solve a real-world problem by evaluating the need, developing solutions, and testing the 'best' one. Their work culminated in a prototype, research poster, podium presentation, and technical report. This program aims to develop students that can utilize the skills acquired in the fellowship to solve relevant problems.

Application to the Design Fellows program is open to undergraduate engineering students at North Carolina A&T. Participants completed an online application which included biographical information (name, academic classification, major, etc.), questions regarding leadership and previous design experience, and a critical thinking assessment. The criteria for selection are listed below:

- Be in good academic standing - a minimum 2.0 cumulative GPA.
- Be a full-time student
- Demonstrate an interest in research and design
- Demonstrate critical thinking skills
- Demonstrate leadership skills

- Have the potential to work well with others
- Have the ability to manage multiple tasks and assignments
- Demonstrate strong communication skills
- Be available to participate in the summer portion of the program

Each day, participants receive brief lectures about various aspects of the engineering design process. They are also given several opportunities to put the information and aspects into practice. The goal is for each team to evaluate a problem and develop a potential solution. There are several milestones throughout the program to ensure progress. They also practice and hone skills that engineers need including communication, team building, and problem solving. Each team was also provided with faculty and industry mentors who can provide experience-based advice for the various projects.

Table 1 provides some demographic information about the 2019 cohort.

Table 1: Program participant demographic information

Total number of participants	6
Academic Year	Freshman – 1 Sophomore – 3 Junior – 2
Academic Major	Bioengineering – 3 Biological Engineering – 1 Computer Engineering – 2

At the culmination of the 5-week program, a focus group and exit survey were used to gather descriptive and interpretive information on the students' feelings of self-efficacy, valuation of engineering knowledge and skills, and engineering identities. The exit survey contained items developed by Walton and Liles [15] and Walton et al. [3] to measure Engineering Values, Self-efficacy, and Identity. The Engineering Values Scale (EVS), contains 8 items arranged on a 7 point Likert scale. The items assess both general and specific aspects of the field of engineering with higher scores reflecting greater valuation. The Engineering Self-Efficacy Scale (ESES), contains 14 items arranged on a 7 point Likert scale. The items assess a general form of self-efficacy as well as self-efficacy directly related to engineering design with higher scores representing greater self-efficacy. The Engineering Identity Scale (EIDS), contains 9 items arranged on a 5 point Likert scale. The five of the items assess engineering identity salience and four of the items assess engineering identity prominence. An 8-item index of extracurricular engineering-related activities was also included in the survey. The focus group lasted approximately 75 minutes. The script was comprised of six discussion questions designed to elicit conversation related to the students' understanding and efficacy in relation to the design process valuation of engineering and their emerging identities as engineers.

Results

Tables 2 – 4 present descriptive information gathered from the exit survey. As can be seen in Table 2, the Design Fellows on average reported a relatively high level of engineering values with an overall mean of 5.9 across all scale items. This suggests that after participation in the program, the design fellows on average "Agreed" with the value assessed by the survey item. One important exception appears to be in relation to computer programming skills where the fellows expressed a noticeably lower amount of value assigned to programming skills.

As can be seen in Table 3, the Design Fellows expressed some degree of doubt or skepticism in relation to their identity as an engineer. In particular, the first three items in the table which measure identity prominence (or importance in relation to other identities in the self-concept), suggest that the design Fellows are unclear regarding the extent to which their identity as an engineer is one of the more important identities they have. The five items at the bottom of the table which measure identity salience (or the likelihood that the identity is activated across contexts) however reflect somewhat higher scores. This suggests the Fellows' identities as engineers are relevant within their social interactions across multiple contexts.

As can be seen in Table 4, the Design Fellows on average reported a moderately high level of engineering self-efficacy with an overall mean of 5.44 across all scale items. This suggests that the fellows on average "Somewhat Agreed" or "Agreed" with the statement assessing their perceived capability in each of the areas assessed by the survey item. Especially notable are the Fellows' response to the question gaging whether they feel they "understand the design process" where the item mean was 6.2. Important exceptions to this general trend are found in noticeably lower self-efficacy beliefs in relation to manipulating components and devices, building machines, and the quality of their capstone design.

Table 2: Engineering Values

Survey Item	Item Mean	Item Scale
Strong math abilities will enhance my career	5.6	1=Strongly Disagree 2=Disagree 3=Somewhat Disagree 4=Neither Agree nor Disagree 5=Somewhat Agree 6=Agree 7=Strongly Agree
Strong abilities to identify industry and social needs will enhance my career	6	
A degree in engineering will allow me to obtain a well-paying job	6.2	
A degree in engineering will give me the kind of lifestyle I want	5.8	
Strong programming skills will enhance my career	5.2	
A degree in engineering will allow me to get a job where I can use my talents and creativity	6	
A degree in engineering will allow me to obtain a job that I like	6.2	
A degree in engineering will allow me to improve peoples' lives	6.2	
Overall Average Engineering Values Score	**5.9**	

Note: N=5

Table 3: Design Fellows Engineering Identity Scores

Survey Item	Mean	Item Scale
Being a professional engineer is an important part of my self-image	3.4	1=Strongly Disagree 2=Disagree 3=Neither Agree nor Disagree 4=Agree 5=Strongly Agree
Being a professional engineer is an important reflection of who I am	3.6	
I have come to think of myself as an engineer	3.6	
I have a strong sense of belonging to the community of engineers	4.3	
How likely are you to discuss your desire to be an engineer with each of the following people:		
A Co-worker	4	1=Extremely Unlikely 2=Unlikely 3=Neither Unlikely nor Likely 4=Likely 5=Extremely Likely
A friend	4.4	
A friend of a friend	4	
A family member	4.4	
A person you are romantically attracted to	4.6	
Overall Mean Engineering Identity Score	4.0	

Note: N=5

Table 4: Design Fellows Engineering Self-Efficacy Scores

Survey Item	Mean	Item Scale
I understand the design process	6.2	
I have the capability to accomplish design	5.8	
I have the capability to evaluate a proposed design solution	6	
I have the capability to recognize changes needed for a design solution	6	
I can work with machines	5.4	1=Strongly Disagree
I can manipulate components and devices	4.6	2=Disagree 3=Somewhat Disagree
I can build machines	4.6	4=Neither Agree nor Disagree
I can disassemble things	6	
I can assemble things	5.2	5=Somewhat Agree
I have the capabilities to identify industry and social needs	6	6=Agree 7=Strongly Agree
My capstone project is professional quality	4.7	
I have the knowledge required to be a professional engineer	5	
I have the skills to be a professional engineer	5.4	
I can succeed as a professional engineer	5.2	
Overall Mean Engineering Self-Efficacy Score	**5.44**	

Note: N=5

Analysis of the themes that emerged from the focus group was used to complement the descriptive information from the exit survey above. Regarding self-efficacy and understanding of the design process, the students described the importance of patience and the value of recognizing that failure is implicit in the design process. They described how the program helped them realize that it is important to be comfortable with failure and flexible enough to respond instead of reacting to failure. For instance, one student suggested that within the design process:

"…failure is a prerequisite."

Another participant described how design involves a repetitive:

"…not getting it right" and then "…doing it over and over until you do."

This understanding that failure is inherent within the design process allowed students to note the value of spending time up-front thinking about where the product or process might fail if a given design solution is pursued. Relatedly, the students described the teamwork they engaged in during the program as reinforcing the need to be open to new ideas and ways of approaching a given problem. In regard to engineering design, the participants seemed to each echo the sentiment that **the design process characteristically involves frequent failure, flexibility collaboration, and a lot of time.**

In regard to engineering values, the focus group conversation centered on a sort of newfound valuation of what one participant referred to as:

"fundamental knowledge"

This fundamental knowledge refers to the math and sciences courses required by the program and the student described a sort of awakening to the importance and relevance of this subject matter. They described how they underestimated the importance of the material taught in their math and science courses. But having the opportunity to use this knowledge in the design process increased their value of math and science content knowledge. Next, the students described the strong valuation of the:

"engineering mindset"

Students described sharing this mindset with other engineers and they felt strongly that this mindset impacted their everyday lives as well as their course work.

The design fellows participating in the focus group also discussed their emerging identities as engineers. They talk together about how "being" an engineer changes the way one approaches problems. One participant described how engineers:

"use a more analytical approach"

…when approaching a problem whether it be an engineering-related problem or a problem they face in their everyday life. They described how others around them were very different in this regard. They see this as one of the many things they share with other engineers, not the least of which is:

"working to solve human problems"

Each of the design fellows also described how while growing up they were often around engineers. In fact, each of the participants grew up with engineers or "engineer-types" in their immediate family. In contrast to these *in-group* experiences that reflect the students' emerging engineering identities, the discussion also turned-up clear evidence that the students had identified *out-groups.* The discussion of this facet of their engineering identity focused on the differences they saw between themselves as engineers and (1) business and finance majors, (2) people who are just in school because others expect them to be, and (3) people who believe the purpose of going to college is to socialize and become popular.

Discussion

This work utilized a mixed method research design to further understand how participants' feelings of self-efficacy, valuation of engineering knowledge and skills, and engineering identities are experienced in an engineering design program. The information drawn from this study provides us with a greater understanding of how undergraduate engineering students experience their educational programs. This information can be used to further develop and enhance the RED Design Fellows program as well as enhance how we communicate with emerging engineers. Self-efficacy is defined as one's beliefs that he or she has the ability, strength, and determination to engage with a given environment and succeed [8]. Ironically, the research reported here suggests that providing engineering students with opportunities to fail may open-up opportunities for faculty to coach them through the failure process, thus enhancing self-efficacy. Researchers often make the distinction between held and assigned values [16], such that held values represent ideal states of being and guiding principles in one's life; while assigned values represent a valuation of some specific object, place, or thing. This was reflected in the students' conversations about how their experience in the Design Fellows program increased the value they assigned to the knowledge they gain in their math and science classes. As previously noted, design-based learning programs are well-suited to have participants "become active learners" [2]. They allow students to apply skills and knowledge to seemingly unrelated problems. Relatedly, the Design Fellows program appears to have helped students more clearly recognize the value they hold for the mindset they shared with other engineers. Evidence from this study also points to the relevance that students' emerging engineering identities have to their experiences. Identity is often defined as meanings attached to the self that position one within groups and networks of relationships [17]. Each of the focus group participants described how they saw their role as engineering students in similar ways. For instance, it was very apparent that they had internalized an expectation of being a committed student who spends a considerable amount of time studying and participates in campus social activities (formal and informal) in limited ways. This would seem to hint at an important opportunity faculty and administrators may have to create opportunities for engineering students that combine learning and academic work with socialization. This work also provides excellent feedback for the curricular changes implemented by the North Carolina A&T RED project. With this, we can course-correct and adjust to provide an optimal learning experience for our students.

References

[1] S. Chandrasekaran, J. M. Long and M. A. Joordens, "Evaluation of student learning outcomes in fourth year engineering mechatronics through design based learning curriculum," in *2015 IEEE Frontiers in Education Conference (FIE),* El Paso, TX, Oct 2015, pp. 1-7.

[2] C. E. Hmelo-silver, "Problem-Based Learning: What and How Do Students Learn?" *Educational Psychology Review,* vol. 16, *(3),* pp. 235-266, 2004.

[3] T. N. Walton, S. B. Knisley and M. B. A. McCullough, "Board 154: Model-building in engineering education," in *2019 ASEE Annual Conference & Exposition,* Tampa, FL, June 15, 2019.

[4] U. Bronfenbrenner, "Toward an experimental ecology of human development," *Am. Psychol.,* vol. 32, *(7),* pp. 513-531, 1977.

[5] U. Bronfenbrenner, "Developmental ecology through space and time: A future perspective," in *Examining Lives in Context: Perspectives on the Ecology of Human Development*, P. Moen, G. H. Elder and K. Lüscher, Eds. Washington, DC, US: American Psychological Association, 1995, pp. 619-647.

[6] U. Bronfenbrenner and P. A. Morris, "The bioecological model of human development," in *Handbook of Child Psychology: Theoretical Models of Human Development*, 6th ed., W. Damon and R. M. Lerner, Eds. Hoboken, NJ, US: John Wiley & Sons Inc, 2006, pp. 793-828.

[7] S. H. Schwartz, "An Overview of the Schwartz Theory of Basic Values," *Online Readings in Psychology and Culture,* vol. 2, *(1),* 2012. Available: http://scholarworks.gvsu.edu/orpc/vol2/iss1/11. DOI: 10.9707/2307-0919.1116.

[8] A. Bandura, *Self-Efficacy: The Exercise of Control.* (1st ed.) New York, NY, US: W. H. Freeman and Company, 1997.

[9] P. Burke and J. E. Stets, *Identity Theory.* (1st ed.) New York, NY: Oxford Univ. Press, 2009.

[10] (November 2018). *Criteria for Accrediting Engineering Programs, 2019 – 2020 | ABET*. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/.

[11] G. Voland, *Engineering by Design.* (2nd ed.) Upper Saddle River, NJ: Pearson/Prentice Hall, 2004.

[12] M. Savin-Baden and C. Howell, *Foundations of Problem-Based Learning.* (1st ed.) Berkshire: McGraw-Hill Education, 2004.

[13] B. Jones *et al*, "The Effects of a Collaborative Problem-based Learning Experience on Students' Motivation in Engineering Capstone Courses," *Interdisciplinary Journal of Problem-Based Learning,* vol. 7, *(2),* 2013. Available: https://docs.lib.purdue.edu/ijpbl/vol7/iss2/2.

[14] J. Rohde *et al*, "Design Experiences, Engineering Identity, and Belongingness in Early Career Electrical and Computer Engineering Students," *IEEE Transactions on Education,* vol. 62, *(3),* pp. 165-172, 2019.

[15] T. N. Walton and R. G. Liles, "Board 157: Designing engineers student survey: Instrument development and preliminary psychometric data," in *2018 ASEE Annual Conference & Exposition,* Salt Lake City, UT, Jun 23, 2018.

[16] D. C. Fulton, M. J. Manfredo and J. Lipscomb, "Wildlife value orientations: A conceptual and measurement approach," *Human Dimensions of Wildlife,* vol. 1, *(2),* pp. 24-47, 1996.

[17] S. Stryker, *Symbolic Interactionism : A Social Structural Version.* (1st ed.) Menlo Park, CA: Benjamin Cummings, 1980.