2018 ASEE Annual Conference & Exposition
Paper ID #22372

Designing Engineers Student Survey: Instrument Development and Preliminary Psychometric Data

Dr. Tobin N. Walton, North Carolina A&T State University

My research is focused on developing interdisciplinary theoretical frameworks and methodological designs capable of modeling the social and psychological drivers of behavior, decision-making, and information processing across multiple domains (e.g., health, education, the workplace).

Dr. Robin Guill Liles, North Carolina A&T State University

Robin Guill Liles is a professor in the Department of Counseling at North Carolina A&T State University. She is also Co-PI for the IUSE/PFE:RED: A Revolution in Engineering Education Motivated by Needs and Design and the Associate Director for Assessment for the ERC for Revolutionizing Metallic Biomaterials.

Designing Engineers Student Survey: Instrument Development and Preliminary Psychometric Data

The Revolutionizing Engineering and computer science Departments (RED) grants program encompasses the National Science Foundation's initiative to encourage and support programmatic changes within engineering and computer science departments aimed at improving undergraduate STEM education (Improving Undergraduate STEM Education [IUSE]; n.d.a.). One way to accomplish this initiative is to model educational practices after the innovative research and development processes characteristic of engineering businesses. According to [1], *innovators* within the engineering business model tend to be risk-averse, spending time and money on those innovations designed to address well-defined, specific needs. By contrast, engineering educators have traditionally focused upon knowledge creation and technological exploration, with less regard for market needs, associated cost, regulatory hurdles, etc. If engineering and computer science programs align with the *innovators' order*, then students would first identify a social and/or industry need and then through coursework, obtain the knowledge and design skills to solve the need.

The College of Engineering at North Carolina Agricultural and Technical State University (NCAT) has historically been the largest producer of African American engineers in the United States. Looking for ways to continue this important educational trend among this under-represented population is important both for reasons of equity and because students from diverse backgrounds bring new perspectives and ideas that may yield engineering solutions to complex global problems [2]. Under investigation with the RED grant at NCAT is whether aligning courses with the *innovators' order* through curricular changes that include design education across all four undergraduate years will empower students to become innovators by enhancing their (a) identity as engineers, (b) valuing of engineering as a profession, and (c) feelings of self-efficacy. Argued here is the notion that students who are able identify important needs, and are imbued with the knowledge and design skills to develop a solution to the need, will feel more capable as engineers (self-efficacy), begin to see themselves as engineers (engineering identity), and increasingly value engineering as an important set of skills, body of knowledge, and career choice. This idea is all important in view of other research suggesting that some engineering education venues are advancing an ecology of social detachment, with ever decreasing regard for social concerns [3].

In experimental terms, the curricular changes (i.e., instituting needs finding and design across four undergraduate years) will constitute the independent variable with educational outcomes (e.g., GPA, retention, enrollment), as dependent variables. These curricular changes will emphasize flip-ordering current curricular pathways, whereby students first find a need and then seek a solution within the context of the classroom. In addition to promoting innovation and understanding of the design process, the implementation of these new educational practices are grounded in a theoretical framework that suggests they will enhance students' (a) beliefs about their own capabilities, (b) identities as engineers, and (d) engineering values. Though traditional summary data of educational outcomes will be collected for evaluation of the projects success, psychometric survey-based measures of these social psychological outcomes will also be operationalized as dependent variables, thus providing both quantitative and qualitative assessments. A vital first phase of this RED project then involves the development of the psychometric scales (i.e., testing of the tests), that will be used.

Although researchers have developed a number of survey-based measures of social psychological aspects of the learning process, and recent efforts have been made to assess causal models of the multiple social psychological influences on educational and career outcomes within the area of engineering [cf. 4, 2, 5]. Importantly, the majority of these studies have been conducted on the campuses of Primarily White Institutions (PWIs). The purpose of this paper is to describe initial development of the Engineering Self-Efficacy Scale (ESES), Engineering Identity Scale (EIDS), and Engineering Values Scale (EVS) using a sample of undergraduate students attending a large public HBCU (Historically Black College or University). Item development, testing procedures, preliminary psychometric properties of the scales, and an initial multi-model comparison using Structural Equation Modeling are detailed below.

Engineering Student Self-Efficacy, Identity, and Values

Self-efficacy

Disparities in representation among underrepresented populations and women have been noted in engineering educational venues. Certain variables (e.g., ability) have been touted to explain this unfortunate reality; however, cognitive influences such as self-efficacy have also been examined [6]. Self-efficacy, a subset of the broader social cognitive theory [7], is a motivator to learning and can be defined as a person's belief that he or she has the ability, strength, and determination to engage with the environment and succeed [8]. Bandura [9] argued that as individuals experience greater self-efficacy, the more likely they are to persist and to succeed. Subsequent educational research appears to support Bandura's position, indicating that academic self-efficacy is a strong predictor for academic success among undergraduate engineering students [5].

A number of researchers have operationalized self-efficacy within the domain of engineering to cover both general facets of self-efficacy, as well as task or skill-specific facets of the construct [10,11,12,13]. Of interest to this study are students' general perceptions of their self-efficacy to become professional engineers, possessing the ability to identify societal and industry needs, and corresponding design solutions. We posit that by consistently providing undergraduate engineering students with opportunities to identify real societal needs and design potential solutions, their feelings of self-efficacy will increase; and so in turn, their classroom academic performance will be enhanced.

Engineering Values

Values can be thought of as guiding principles in one's life, and the relative importance of a given set of values guides one's actions [see 14]. This axiom is certainly true within an academic context [15]. Undergraduate students who value engineering education and the engineering profession are more likely to self-select into engineering programs and to succeed [16]. Cech [3], further suggested that engineering students who appreciate the relationship between their education and their future contributions to society through technological innovation tend to pursue academic and scientific work which has some attached social value. By contrast, engineering students who do not make this connection are more likely to view their engineering education as stale, boring, and task-driven, with any related social implications as tangential to their work, at best.

Martin [17] provided commentary upon the importance of finding personal meaning in one's work and how such meaning can give way to "intelligibility and value." Individuals who can link what they value with what they do bring a heightened sense of commitment and motivation to their efforts, likely resulting in greater productivity and pride in product. Though Martin speaks specifically to personal valuing of engineering as a profession, engineering students may also possess such deeply-held commitments to the profession of engineering. We posit that by consistently providing undergraduate engineering students with opportunities to identify real societal needs and design potential solutions, their valuation of engineering will increase; and so in turn, their classroom academic performance will be enhanced.

Engineering Identity

Identities are meanings attached to the self-concept that position individuals within networks of relationships and organizational and social structures [18]. They are built-up from social interaction and influence behavior and behavioral change through the process of self-verification [19]. Students who identify as engineering students and soon-to-be professional engineers are more likely to matriculate their course of study, culminating in successful graduation [20]. Developmentally-speaking, identity formation is a dynamic and vibrant process, evolving out of interactions between individuals and significant others, preferences and predilections, and contextual influences [21]. Consequently, engineering programs have the potential to inculcate engineering identity [22]. Identifying as an engineering student or future professional engineer has programmatic implications as well. Jungert [23] studied students' evolving engineering identities and discovered that students often fused pride in their programmatic experiences with pride in their emerging professional expertise. We posit that by consistently providing undergraduate engineering students with opportunities to identify real societal needs and design potential solutions, students will be exposed to the types of social interactions and feedback from significant others that build strong engineering identities. This in turn will enhance their classroom academic performance as students seek continued self-verification as an engineer [18].

Bronfenbrenner's Ecological Theory

According to the Ecological Theory of Human Development [24], human development involves complex interrelationships among four concepts: process-person-context-time.

Bronfenbrenner and Morris [25] theorized that development evolves out of *processes* (e.g., interactions) occurring in *context*. In our overall RED project we are interested in the interactions between students and instructors, as well as between students and “objects and symbols” (e.g., design project) within their *microsystems* (e.g., classroom, laboratory, etc.) [26]. These *proximal processes* have the potential to powerfully influence student development [27]. The curricular changes we will implement constitute *proximal processes* or, interactions between individuals and the people, objects, and symbols within their immediate environments, occurring on a regular basis over *time*.

Within Ecological Theory engineering values, self-efficacy, and identity operate within the realm of the *Person* consisting of *force, resource,* and *demand* characteristics. *Person force* characteristics are developmentally-instigative or –disruptive behaviors which can forward or hinder development. Within engineering education, developmentally-instigative behaviors might be things like attending facilitated study groups, engineering conferences, and internships. We assume that engineering values, self-efficacy and identity motivate engagement in these types of developmentally-instigative behaviors. That is, as students’ valuation of engineering, engineering self-efficacy, and engineering identities become stronger so in turn do students engagement in developmentally-instigative behaviors. Importantly however, whereas self-efficacy beliefs and identities are typically shown to be relatively proximal influences (and outcomes) on behavior, values are more distal, operating instead as guiding principles of behavior and general outcomes of past behavior [14,17].

In addition to the propositions that values, identities and self-efficacy are motivators of behavior, a number of researchers have pointed to the notion that these relationships are likely reciprocal, constituting a feedback loop. That is, not only do strong values, self-efficacy beliefs and identities motivate behavior, but engaging in developmentally instigative behaviors become self-verifying experiences [19,28]. This self-verifying process increases the likelihood of consistent engagement in similar types of behaviors in the future, and should result in more general achievement outcomes (e.g., persistence to graduation, improved GPA). In other words, we posit that increases in short and long-term student learning are mediated by experiences that help students identify needs and develop design solutions (i.e., developmentally instigative behaviors). These experiences in turn enhance students' valuation of engineering, beliefs about capabilities, and identification as an engineer; motivating future behaviors. Like a cybernetic system then [29], these processes repeat and are self-regulating. Several basic hypotheses will be used to assess both the validity of the scales used to measure engineering values, self-efficacy, and identity and the plausibility of this theoretical framework. Students who engage in more engineering related activities (e.g., attending an engineering conference, facilitated study group, or internship) will:

(H1) more highly value engineering as a set of skills and abilities, as a career choice, and way to improve peoples' lives (i.e., engineering values).

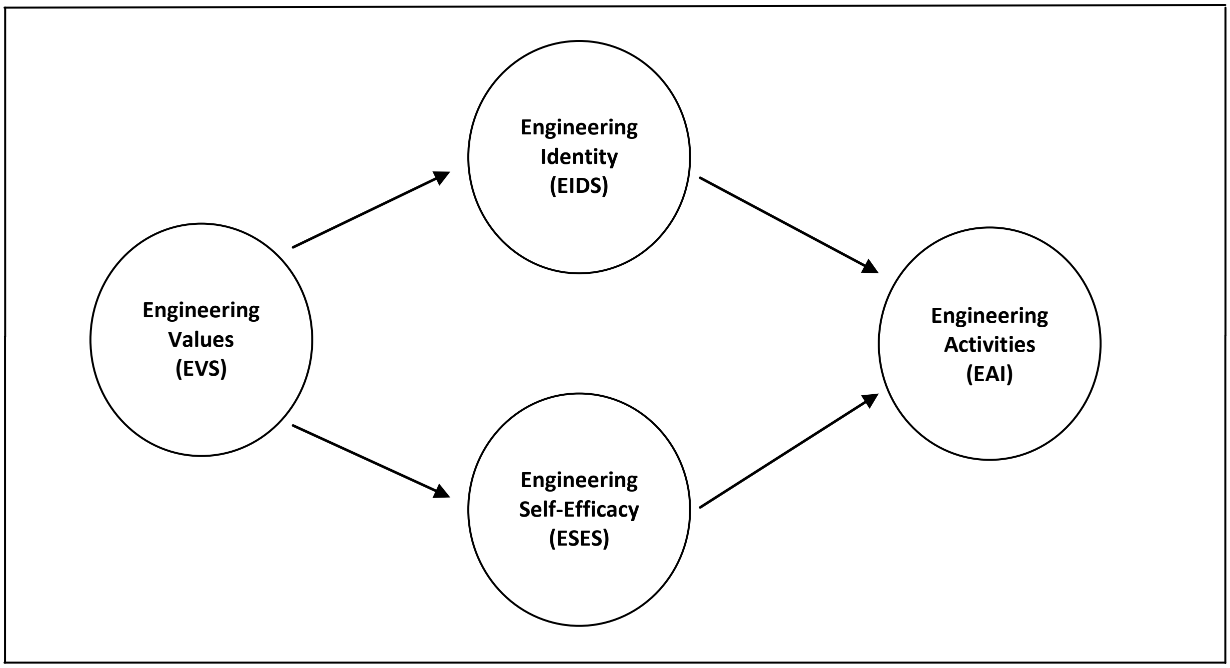
(H2) have more positive beliefs about their ability (i.e., self-efficacy), to accomplish the things needed to succeed as an engineering student and professional engineer.

(H3) more strongly identify as an engineer (i.e., engineering identity).

(H4) More positive beliefs about one's own abilities to succeed as and engineering student (self-efficacy), and more strongly identifying as an engineer (engineering identity), act as intervening influences between engineering values engaging in engineering related activities (Figure 1).

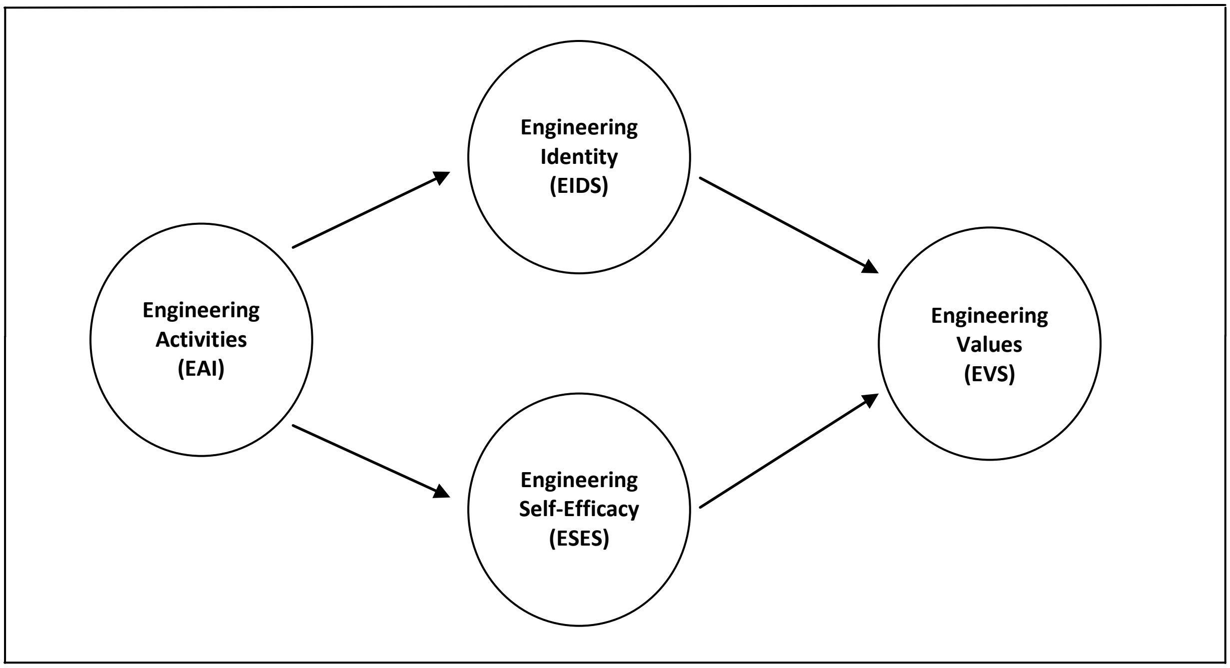
(H5) The relationship between engineering values an engagement in engineering activities is reciprocal constituting a feedback loop. That is, engagement in engineering activities reinforces engineering values through engineering self-efficacy and identity (Figure 2).

Figure 1. Hypothesized Model 1: Engineering Values and Engineering Self-Efficacy Intervening



Note: Standardized principal component scores were used to represent each construct in the SEM. EVS=Engineering Values Scale, ESES=Engineering Self-Efficacy Scale , EIDS=Engineering Identity Scale, EAI=Engineering Activities Index. $N = 406$

Figure 2. Reverse Causation Hypothesized Model R4: Engineering Identity and Engineering Self-Efficacy Intervening



Note: Standardized principal component scores were used to represent each construct in the SEM. EVS=Engineering Values Scale, ESES=Engineering Self-Efficacy Scale ,EIDS=Engineering Identity Scale, EAI=Engineering Activities Index. *N* = 406

Methods

In the *first stage* of this study we used web-based survey data obtained from a small sample of undergraduate engineering majors (*N*=44), to conduct an *a priori* power analysis. Half of this sample was drawn at random from students currently enrolled in introductory general engineering and design courses, and half were students who voluntarily attended an informative meeting about a student-based engineering organization on campus. In the *second stage*, we again used web-based survey data, but drew a larger sample (*N*=406), of undergraduate engineering majors currently enrolled in introductory general engineering and design courses[i]. In this stage we conducted item-analyses, alpha reliability testing, and Principal Components Analysis (PCA) to develop the scale measures of each construct (i.e., engineering values, self-efficacy, and identity). Then we used information obtained from the power analysis to draw random subsamples of the optimal size (see *Stage 1* below), to test hypotheses 1-3 by assessing the bivariate correlations between each of the scales and an index of self-reported engagement in a variety of engineering activities. In the *third stage* we tested H4 and H5 by conducting an information-based multi-model comparison [30], using a series of Structural Equation Models (SEMs), to assess the most plausible causal ordering of the constructs in the model (i.e., H4 and H5).

Stage 1

Null Hypothesis Statistical Testing (NHST) has been strongly criticized because statistical significance does not necessarily equate to substantive meaning or practical importance [31,32]. Furthermore, in any test of statistical significance, the probability of committing both *Type I* (false positive) and *Type II* (false negative) errors is dependent upon the (unknown) population effect size (*ES*), significance level (α), statistical power level (1-β), and sample size (n). Thus, "…when any three of them are fixed, the fourth is determined" [37,p 98]. When using NHST, an effective way to minimize the probability of committing *Type I* and *Type II* errors and ensure that significant results reflect important substantive meaning, is to conduct an *a priori* power analysis to determine an optimal sample size given an expected effect size [37, 34]. Below we discuss an *a priori* power analysis conducted prior to testing the engineering values, self-efficacy, and identity scales.

To determine a meaningful Effect Size (*EF*), that our scales of engineering values, self-efficacy, and identity need to be able to detect we conducted an a priori power analysis using a small purposive sample (N=44) of current engineering students. We assumed that participating in extra-curricular engineering activities (e.g., summer enhancement programs, facilitated study groups, attending engineering conferences, internships) are important developmentally-instigative behavioral practices through which students internalize strong engineering values, self-efficacy beliefs, and identities which in turn motivate learning. A web-based questionnaire was designed to assess the number of extra-curricular engineering activities students' had participated within the last year. Half of the sample (*n*=22), were randomly selected students who completed the questionnaire during an introductory engineering course, while the other half (*n*=22), were engineering students who completed the questionnaire while voluntarily attending an interest meeting of a student-based engineering organization on campus. We assumed that the subsample of students who voluntary attended the engineering organization meeting would have internalized stronger engineering values, self-efficacy beliefs, and identity, than students in the other subsample. Consequently, by comparing the two groups on the mean number of extra-curricular activities engaged in within the last year, we can get a basic understanding of a meaningful *EF* that our measures of values, self-efficacy, and identity will need to detect when using the full sample (Stage 2). This in turn will allow us to use an optimal sample size that minimizes the likelihood of both Type I and Type II errors and ensures our tests of statistical significance are substantively meaningful.

Although standardized estimates of (*EF*) are sometimes appropriate (e.g., *Cohen's d, eta*), the raw difference between means is generally sufficient when the measures involved are intuitively meaningful [35]. As expected students attending the organization meeting on average reported engaging in approximately 1.5 more engineering activities ($\bar{x}$ = 2.41) than students from the introductory engineering courses ($\bar{x}$ = .86), on an activities index with a range of 0 - 6. Substantively, we judged this to reflect a small to medium *EF*. The results of an independent samples t-test confirmed that the difference in means between the two groups was statistically significant $t(34) = 4.16$, $p<.001$. Considering each of these pieces of evidence we decided to assume that a small-to-medium effect size (*EF* = .2), would be appropriate for the initial tests of our measures of engineering values, self-efficacy, and identity. This *EF* along with α=.05 and $1-\beta$=.80 were entered into the GPOWER software program which calculated an optimal sample size of (n = 262) for one-tailed correlation tests [36,37,34].

Stage 2

In the *second stage*, we drew a larger sample (N=406), and administered the web-based survey instrument to undergraduate engineering majors currently enrolled in one of 6 introductory general engineering and design courses. During a regular class session (all on the same day), instructors of each course disseminated a link to their students via the course learning platform. Students were asked to click on the link, redirecting them to the survey which took approximately 15 minutes to complete. Table 1 contains information describing the sample. In total 406 completed surveys were collected. The sample was comprised of primarily Black (82.2%), Male (68.9%), Freshman (82%), engineering majors.

Measures

Engineering Activities Index (EAI). Students were provided with a list of seven extra-curricular engineering related activities and asked to indicate each of the activities they "participated in during the past year". Possible activities included: joining an engineering organization, attending activities sponsored by your department or college, attending a summer enhancement program, participating in a facilitated study group, visiting an engineering program, attending an engineering conference, and any other activity not listed.

Table 1. Descriptive Statistics

Variable	Percentage of Sample
Race/Ethnicity	
Black	82.2%
White	3.9%
Other	13.8%
Household Income	
< 40,000	27%
40,000< > 80,000	36%
>80,000	28%
Sex	
Female	28.5%
Male	68.9%
Other	2.6%
Employment Status	
Working Full Time	2.5%
Working Part Time	23.9%
Unemployed (Looking for work)	31.5%
Unemployed (Not looking for work)	36.9%
Mothers Highest Level of Education	
High School	28.1%
Associates Degree	10.3%
Bachelors Degree	26.6%
Masters Degree	22.9%
Doctoral Degree	4.2%
Year in School	
Freshman	82%
Sophomore	8.9%
Junior	3.4%
Senior	1.2%
Graduate/Other	3.7%
Academic Program	
Civil, Architectural and Environmental Engineering	23.4%
Chemical, Biological, and Bio Engineering	19%
Electrical and Computer Engineering	18.7%
Mechanical Engineering	28.1%
Computational Science and Engineering	1.7%
Industrial and Systems Engineering	6.2%
Computer Science	2.5%

Note: N=406

Engineering Values Scale (EVS). A measure of engineering values was developed by reviewing the engineering education literature and consulting with engineering faculty on the research team. Students were asked their level of agreement with eight value statements. Three statements targeted valuation of engineering skills: strong math abilities will enhance my career, strong programming skills will enhance my career, strong abilities to identify industry and social needs will enhance my career. Five of the statements targeted valuation of engineering as a career choice: a degree in engineering will allow me to (a) obtain a well-paying job, (b) obtain a job I like, (c) give me the kind of lifestyle I want, (d) allow me to use my talents and creativity, and (e) improve peoples' lives. Responses were ordered on a seven point Likert scale with higher values indicating greater valuation of engineering.

Engineering Self Efficacy Scale (ESES). A measure of engineering self-efficacy was developed by reviewing the engineering education literature [5], and consulting with engineering faculty on the research team. Students were asked their level of agreement with the following six statements: I understand the design process, I have the capabilities to accomplish design, I have the capabilities to identify industry and social needs, I have the knowledge required to be a professional engineer, I have the skills to be a professional engineer, and I can succeed as a professional engineer. Responses were ordered on a seven point Likert scale with higher values indicating greater self-efficacy.

Engineering Identity Scale (EIDS). A measure of engineering identity was developed by adapting indicators of identity salience and prominence from the broader social psychology literature [37]. Five items assessed the salience of an engineering identity by asking students to reflect on how likely they would be to discuss their desire to be an engineer with each of the following people: "A co-worker", "A friend", "A friend of a friend", "A family member", "A person of the opposite sex". Four items assessed the prominence of an engineering identity by asking students their level of agreement with the following statements: "Being a professional engineer is an important part of my self –image", "Being a professional engineer is an important reflection of who I am", "I have come to think of myself as an engineer", "I have a strong sense of belonging to the community of engineers". Responses were ordered on a five point Likert scale with higher values indicating a stronger engineering identity.

Descriptive Statistics. Table 2 presents summary descriptive statistics for the Engineering Activities Index (EAI), Engineering Values Scale (EVS), Engineering Self-Efficacy Scale (ESES), and the Engineering Identity Scale (EIDS). The most frequently reported number of activities students in the sample reported in was 1 out of a possible seven, with a sample mean of 1.3 (*SD* = 1.21*)* activities. This relatively low level of engagement is to be expected given that the overwhelming majority of the sample was freshman, relatively new to campus and the College of Engineering. On the EVS, the sample mean ($\bar{x}$=49.5, *SD*=6.11) suggests that student responses across the eight engineering value statement items averaged around 6.2 for each item on a seven point scale. Thus students on average "agreed" with each of the 8 value statements, indicating a relatively high degree of valuation of engineering. Sample mean on the ESES ($\bar{x}$=31.0, *SD*=8.56) suggest that student responses across the 6 self-efficacy items averaged around 5.17 for each item on a seven point scale. Thus students on average "somewhat agreed" with each of the statements assessing their beliefs about their engineering capabilities, indicating a moderate degree of self-efficacy. Lastly, the average student in the sample "somewhat agreed" with each of the nine identity items. Indeed, the mean on the EIDS ($\bar{x}$=36.5, *SD*=6), suggests that student responses across the nine items averaged around 4.05 on a five point scale. Overall these results are to be expected. Specifically, it makes sense that Freshman engineering students begin their programs optimistically; highly value engineering as a field and career choice, yet having had relatively few opportunities to engage in engineering activities, having cautious views about their capabilities, and only minimally seeing themselves as engineers.

Table 2. Summary Statistics for Scales and Indices

Scale Or Index	Sample Mean (Mean)	SD	Possible Range	Mode	Items	Scaling
EAI	1.3	1.21	0-6	1	6	Count
EVS	49.5	6.11	8-56	48	8	7pt
ESES	31.0	8.56	6-42	36	6	7pt
EIDS	36.5	6.0	9-45	38	9	5pt

Note: EAII=Engineering Activities Index; EVS=Engineering Values Scale, ESES=Engineering Self-Efficacy Scale, EIDS=Engineering Identity Scale. *N*=406

Scale development. Next we turn to an analysis of the psychometric properties of each of the scales. We examined inter-item correlations and calculated a Cronbach's *alpha* in order to assess the internal consistency of each scale, and we conducted Principal Components Analysis (PCA), to assess their unidimensionality and derive component scores to be used in later analyses. PCA is a quantitative methodology for scale development that is more inductive than Factor Analysis (FA), and it is thus, more appropriate for this early stage in the development of these scales. Indeed, PCA models the items in a scale as independent variables from which components are extracted, whereas FA models the items as dependent variables that are "caused" by independent latent factors [38]. As a more exploratory methodology, PCA better corresponds to our current research needs.

Beginning with the reliability analysis of the EVS, inter-item correlations ranged from a low of r=.285 to a high of r=.719, and corrected-item total correlations from a low of r=.444 to *r*=.753 (not reported). Cronbach's *alpha* for the EVS was strong (α=.865), equating to an estimated measurement error of (*e*=.267). Unrotated Principal Component (PC) loadings for the EVS are presented in Table 3. All items loaded strongly on a single PC which explained a total of 54% of the variance across all of the items. Combined, these results provide solid evidence that the EVS has a high degree on internal consistence and is measuring a single, unidimensional construct.

Strong results were also found for the ESES. Inter-item correlations on the ESES ranged from a low of *r*=.338 to a high of *r*=.737, and corrected-item total correlations from a low of *r*=.554 to *r*=.736 (not reported). Cronbach's *alpha* for the ESES was strong as well (α=.851), equating to an estimated measurement error of (*e*=.276). All ESES items loaded strongly on a single PC which explained a total of 58.8% of the variance across all of the items. As with the EVS, these results provide solid evidence that the ESES is an internally consistent and unidimensional measurement scale.

Inter-item correlations for the EIDS ranged from a low of *r*=.192 to a high of *r*=.699, and corrected-item total correlations ranged from a low of *r*=.533 to a high of *r*=.637. Cronbach's *alpha* for the EIDS was very high (α=.857), equating to an estimated measurement error of (*e*=.266). Although two PCs were extracted, all EIDS items loaded strongly on the first component ranging from a low of *r*=.615 to a high of *r*=.757, which explained a total of 47.4% of the variance across the items. From this we can conclude that the 1^{st} PC constitutes what [39] refers to as a "size factor" (p. 38), or a situation when all items in a scale load strongly and in the same direction on the 1^{st} PC. This suggests that the 9-item EIDS contains an acceptable level of unidimensionality, and the remaining components extracted are thus interpreted as contrasts. Specifically, because the 1^{st} PC must be orthogonal to all subsequent components the expected pattern of loadings for the 2nd PC will be a mix of positive and negative signs. As can be seen in Table 2, this expectation is confirmed. Indeed the 2nd PC (which explains 18.6% of the total variance within the scale items), appears to represent a contrast between the items assessing the prominence of an engineering identity (positive loadings), and the items assessing the salience of an engineering identity (negative loadings). Again, these results provide solid evidence that the EIDS is an internally consistent and unidimensional measurement scale.

Bi-variate Correlation Tests. Using information obtained from the power analysis (Stage 1), we tested hypotheses 1-3 by assessing the bivariate correlations between each of the scales and an index of self-reported engagement in a variety of engineering activities. Table 4 contains information on the bivariate correlations between the Engineering Activities Index (EAI), and the EVS, ESES, and EIDS across eight randomly drawn subsamples (with replacement) of the optimal sample size (n=262). Surprisingly, using an α criterion of .05, engineering values were only weakly correlated with engagement in engineering activities in just 4 of the 8 eight subsamples (r= .138, r=.12, r=.15, r=.12). Using an α criterion of .10 however, two additional subsamples (subsample #5 & #7), produced weak yet significant correlations between engagement in engineering activities and engineering values (r=.08, r=.09). These results offer weak support for H1 and suggest that engagement in engineering activities is related to students' valuation of engineering, but the relationship within this sample may be smaller than anticipated. A second explanation may relate to the more distal influence theorized to exist between values and behavior (H4). Indeed, if engineering self-efficacy and identity act as intervening influences between values and behavior as hypothesized, direct bivariate correlations between values and behavior would likely be weak.

Table 3. Psychometric Properties for the Engineering Values Scale, Engineering Self-Efficacy Scale, and Engineering Identity Scale.

SCALE	Component Loading	
Engineering Values Scale (α = .865: *e* = .267)	1	2
I am confident that…		
1) Strong math abilities will enhance my career.	.614	-
2) A degree in engineering will allow me to obtain a well-paying job.	.759	-
3) A degree in engineering will give me the kind of lifestyle I want.	.818	-
4) Strong programming skills will enhance my career.	.539	-
5) A degree in engineering will allow me to get a job where I can use my talents and creativity.	.838	-
6) A degree in engineering will allow me to obtain a job that I like.	.819	-
7) A degree in engineering will allow me to improve peoples' lives.	.771	-
8) Strong abilities to identify industry and social needs will enhance my career	.648	-
Variance Explained	54%	
Engineering Self Efficacy Scale (α =.851: *e*=.276)		
I am confident that…		
1) I understand the design process.	.707	-
2) I have the capabilities to accomplish design.	.854	-
3) I have the knowledge required to be a professional engineer.	.686	-
4) I have the skills to be a professional engineer.	.771	-
5) I can succeed as a professional engineer.	.765	-
6) I have the capabilities to identify industry and social needs.	.806	-
Variance Explained	58.8%	
Engineering Identity Scale (**α =**.857: *e*=.266)		
How likely are you to discuss your desire to be an engineer with…		
1) A co-worker.	.699	-.329
2) A friend.	.757	-.365
3) A friend of a friend.	.745	-.268
4) A family member.	.673	-.404
5) A person of the opposite sex.	.742	-.416
6) Being a professional engineer is an important part of my self-image.	.615	.499
7) Being. a professional engineer is an important reflection of who I am.	.647	.581
8) I have come to think of myself as an engineer.	.629	.502
9) I have a strong sense of belonging to the community of engineers.	.699	.433
Variance Explained	47.4%	18.6%

Note. Unrotated Principal Component Solution. *N*=406.

Information in Table 4 also indicates that engineering self-efficacy was weak-to-moderately correlated with engagement in engineering activities across all eight subsamples (median correlation was r=.225). Furthermore the correlations were very highly significant (p<.001), in five of the subsamples and highly significant (p<.01), in the remaining three. This offers solid support for H2. Lastly, the data suggests that engineering identity is weakly, yet consistently, related to engagement in engineering activities. Indeed, the median correlation across the eight subsamples was r=.15, with five subsamples producing highly significant p-values (p<.01), and three producing significant p-values (p<.05). This offers solid support for H3.

Table 4. Bivariate Correlations between the Engineering Activities Index (EAI), and the Engineering Values, Engineering Self-Efficacy, and Engineering Identity Scales.

Scale	Sample #1	Sample #2	Sample #3	Sample #4	Sample #5	Sample #6	Sample #7	Sample #8
EVS	$.138^{*}$	$.12^{*}$	.05	.072	.08	$.15^{**}$	.09	$.12^{*}$
	p=.014	p=.030	p=.217	p=.128	p=.098	p=.008	p=.088	p=.041
	n=251	n=251	n=253	n=252	n=252	n=251	n=254	n=252
ESES	$.21^{**}$	$.22^{***}$	$.23^{***}$	$.26^{***}$	$.20^{**}$	$.23^{***}$	$.30^{***}$	$.20^{**}$
	p=.001	p=.000	p=.000	p=.000	p=.001	p=.000	p=.000	p=.001
	n=234	n=235	n=238	n=240	n=238	n=234	n=240	n=232
EIDS	$.18^{**}$	$.17^{**}$	$.12^{*}$	$.14^{*}$	$.15^{**}$	$.18^{**}$	$.15^{**}$	$.12^{*}$
	p=.003	p=.006	p=.034	p=.017	p=.009	p=.003	p=.011	p=.032
	n=234	n=235	n=238	n=240	n=238	n=234	n=240	n=232

Note: Each subsample was random drawn (with replacement) from the full data set (N=406). Raw scores on the EAI were transformed to standardized (z-scores) EVS=Engineering Values Scale, ESES=Engineering Self-Efficacy Scale, EIDS=Engineering Identity Scale.

Stage 3

Although Null Hypothesis Significance Tests (NHST), such as those reported above can be useful for assessing relationships between constructs, they have important limitations when applied to model building. Namely, NHST assumes that one true model exists in reality, and relies on a single test of the probability of obtaining a given set of data under the condition of the null-hypothesis. Alternatively, information-based approaches postulate multiple models (based on theory and past research), and comparatively assess them via an information criterion statistic (e.g., AIC, BIC), to determine the model that best approximates the data. To test H4 we conducted an information-based multi-model comparison [28], using a series of Structural Equation Models (SEMs), to assess the most plausible causal ordering of the constructs in the model. Within an SEM context, AIC and BIC constitute relative fit indices providing directly comparable parsimony adjusted estimates of the *distance* between the structural model and the data in the correlation/covariance matrix. Lower values of AIC and BIC indicate better and more parsimonious fit.

Figure 1 depicts the Hypothesized Model 1, where engineering self-efficacy and identity act as intervening influences between engineering values and engagement in engineering activities. We also posited two alternative models. Alternative Model 2 positions engineering values and self-efficacy as intervening influences between engineering identity and engagement in engineering activities. Alternative Model 3 positions engineering values and identity between engineering self-efficacy and engineering activities. Information in Table 5 indicates that the Hypothesized Model 1 (*AIC*=14.58; *BIC*=42.62), fits the data better than both Alternative Model 2 (*AIC*=18.32; *BIC*=46.36), and Alternative Model 3 (*AIC*=107.37; *BIC*=135.41). This offers support for H4 and the proposition that self-efficacy beliefs and engineering identity exercise an intervening influence on the relationship between engineering values engagement in engineering activities.

Hypothesis 5 proposes that the relationships between person force characteristics (i.e., engineering values, self-efficacy, and identity), and behavior are reciprocal, constituting a feedback loop. To test this hypothesis we ran three additional models in which the causal ordering was reversed from those models assessing H4. Figure 2 depicts the Reverse Causation Hypothesized Model R4 which positions engagement in engineering activities as an exogenous independent variable influencing the internalization of engineering values through engineering self-efficacy beliefs and identity. Similar to our tests of H4, we also posited two alternative models. Alternative Model R5 positions engineering activities as an exogenous independent variable influencing the internalization of an engineering identity through engineering values and self-efficacy. Alternative Model R6, positions engineering activities as an exogenous independent variable influencing engineering self-efficacy beliefs through engineering values and identity. Information in Table 6 indicates that the Hypothesized Model R4 (*AIC*=14.88; *BIC*=42.92), fits the data better than both Alternative Model R5 (*AIC*=18.67; *BIC*=46.72), and Alternative Model R6 (*AIC*=105.21; *BIC*=133.25). This offers support for H5 and the proposition that the relationship between social psychological motivators of behavior measured in this study (i.e., engineering values, self-efficacy, and identity) and engagement in engineering activities is reciprocal. Namely, not only do strong values, self-efficacy beliefs and identities influence behavior, but those behaviors become self-verifying experiences thereby increasing the likelihood of consistent engagement in similar types of behaviors in the future.

Table 5. Multi-Model Comparison

Model	Exogenous Variable(s)	Intervening (Endogenous) Variable(s)	Dependent Variable	AIC	BIC
Hypothesized Model 1	EVS	EIDS,ESES	EAI	14.58	42.62
Alternative Model 2	EIDS	EVS, ESES	EAI	18.32	46.36
Alternative Model 3	ESES	EVS, EIDS	EAI	107.37	135.41

Note: *N*=406, χ^2=100.14(6), EVS=Engineering Values Scale, ESES=Engineering Self-Efficacy Scale EIDS=Engineering Identity Scale, EAI=Engineering Activities Index.

Table 6. Reverse Causation Multi-Model Comparison

Model	Exogenous Variable(s)	Intervening (Endogenous) Variable(s)	Dependent Variable	AIC	BIC
Hypothesized Model R1	EAI	EIDS,ESES	EVS	14.88	42.93
Alternative Model R2	EAI	EVS, ESES	EID	18.67	46.72
Alternative Model R3	EAI	EVS, EIDS	ESES	105.21	133.25

Note: N=406, χ^2=100.14(6), EVS=Engineering Values Scale, ESES=Engineering Self-Efficacy Scale EIDS=Engineering Identity Scale, EAI=Engineering Activities Index.

Discussion

Improving engineering education requires systematic assessment and evaluation of the impacts that educational initiatives have on students. Toward this end, this paper reports on the development and assessment of survey-based scale measures of three social psychological constructs shown to be motivators of learning. Overall, each of the scales appears to be internally consistent and measuring a single, unidimensional construct. Furthermore, the theoretical framework regarding the relationships between these constructs and behavior appears to be valid, withstanding a multi-model comparative analysis. These are important results because it indicates the importance of understanding the multiple social and psychological influences on student learning. Important next steps in this project will be to gather qualitative data from students and faculty regarding the content of the EVS, ESES, and EIDS. Next, we will draw a (validation) sample of undergraduate engineering majors, and assess the scales and theoretical model using more deductive approaches. Specifically, using a validation sample we will assess the scales using Confirmatory Factor Analysis, and assess the model with Latent Variable Structural Equation Modeling using absolute measures of Model Fit (e.g., χ^2, *RMSEA)*, and the assessment of path coefficients. These measures (along with traditional summary data such as enrollment, retention, and GPA), will then be used to assess the effectiveness of curricular and programmatic changes that will emphasize needs finding and design skills within an undergraduate engineering programs at a large public HBCU (Historically Black College or University).

References

[1] Zenios, S., Makower, J., & Yock, P. (2010) *Biodesign: The process of innovating medical technologies*. Cambridge, UK: Cambridge University Press.

[2] Godwin, A., Potvin, G., Hazari, Z., & Lock, R. (2016). Identity, Critical Agency, and Engineering: An Affective Model for Predicting Engineering as a Career Choice. *Journal of Engineering Education*, 105(2):312-340.

[3] Cech, E.A. (2014). Culture of disengagement in engineering education? *Science, Technology, & Human Values,* 39(1): 42-72.

[4] Bairaktarova, D., & Woodcock, A. (2017). Engineering student's ethical awareness and behavior: a new motivational model. *Science and Engineering Ethics,* 23(4): 1129-1157.

[5] Mamaril, N.A., Usher, E.L., Li, C.R, Economy, D.R., & Kennedy, M.S. (2016). Measuring undergraduate students' engineering self-efficacy: a validation study. *Journal of Engineering Education,* 105(2): 366-395.

[6] Santiago, A.M., & Einarson, M.K. (1998). Background characteristics as predictors of academic self-confidence and academic self-efficacy among graduate science and engineering students. *Research in Higher Education,* 39(2): 163-198.

[7] Bandura, A. (1986). *Social foundations of thought and action*. Englewood Cliffs, NJ: Prentice-Hall.

[8] Howardson, G.N., & Behrend, T.S. (2015). The relative importance of specific self-efficacy sources in pretraining self-efficacy beliefs. *International Journal of Training and Development,* 19(4): 233-252.

[9] Bandura, A. (1997). *Self-efficacy: The exercise of control.* New York, NY: Freeman.

[10] Carberry, A.R., Lee, H.S., & Ohland, M.W. (2010). Measuring engineering design self-efficacy. *Journal of Engineering Education,* 99: 71-80.

[11] Fantz, T.D., Siller, T.J., & DeMiranda, M.A. (2011). Pre-collegiate factors influencing the self-efficacy of engineering students. *Journal of Engineering Education,* 100: 604-623.

[12] Lent, R. W., Miller, M. J., Smith, P. E., Watford, B.A., Hui, K., & Lim, R. H. (2015). Social cognitive model of adjustment to engineering majors: Longitudinal test across gender and race/ethnicity. *Journal of Vocational Behavior*, 86: 77-85.

[13] Schubert, T.F., Jacobitz, F.G., & Kim, E.M. (2012). Student perceptions and learning of the engineering design process: An assessment at the freshmen level. *Research in Engineering Design,* 23: 177-190.

[14] Schwartz, S. H. (2012). An overview of the Schwartz theory of basic values. *Online Readings in Psychology and Culture*, *2*(1). doi:10.9707/2307-0919.1116

[15] Ponton, M.K. (2002). Motivating students by building self-efficacy. *Journal of Professional Issues in Engineering Education and Practice,* 128(2): 54-57.
[16] Li, Q., McCoach, D.B., Swaminathan, H., & Tang, J. (2008). Development of an instrument to measure perspectives of engineering education among college students. *Journal of Engineering Education,* 97(1): 45-55.
[17] Martin, M. (2002). Personal meaning and ethics in engineering. *Science and Engineering Ethics,* 8(4): 545-560.
[18] Walton, T., Jones, R.E. (2017). Ecological Identity: The development and assessment of a measurement scale. *Environment and Behavior,* Online First, 1-33. DOI: 10.1177/0013916517710310
[19] Burke, P. J., & Stets, J. E. (2009). *Identity Theory*. New York, NY: Oxford University Press.
[20] Craig, T. (2013). Conceptions of mathematics and student identity: implications for engineering education. *International Journal of Mathematical Education in Science and Technology,* 44(7): 1020-1029.
[21] Walker, M. (2001). Engineering identities. *British Journal of Sociology of Education,* 22(1): 75-89.
[22] Bergerson, A.A., Hotchkins, B.K., & Furse, C. (2014). Outreach and identity development: new perspectives on college student persistence. *Journal of College Student Retention: Theory & Practice, 16*(2): 165-185.
[23] Jungert, T. (2013). Social identities among engineering students and through their transition to work: a longitudinal study. *Studies in Higher Education*, 38(1): 39-52
[24] Bronfenbrenner, U., (1977) Toward an ecology of human development. *American Psychologist,* 32: 513-531.
[25] Bronfenbrenner, U., & Morris, P. A. (2006). The bioecological model of human development. *Handbook of child psychology*.
[26] Bronfenbrenner, U., (1995) Developmental ecology through space and time: A future perspective. In P. Moen, G.H. Elder Jr., & K. Luscher (EDs.), *Examining lives in context: Perspectives on the ecology of human development.* (pp.619-648). Washington, DC: American Psychological Association.
[27] Trudge, J. R., Mokrova, I., Hatfield, B. E., & Karnik, R. B. (2009). Uses and misuses of Bronfenbrenner's bioecological theory of human development. Journal of Family Theory & Review, 198-210.
[28] Gecas, V., Schwalbe, M. L., (1983) Beyond the looking-glass self: social structure and efficacy-based self-esteem. *Social Psychology Quarterly,* 46(2): 77-88.
[29] Burke, P. J. (2006). Identity change. *Social psychology quarterly*, *69*(1), 81-96.
[30] Burnham, K. P., & Anderson, D. R. (1998). *Model selection and multimodel inference: A practical information theoretic approach*. New York, NY: Springer.
[31] Onwuegbuzie, 2004 Enhancing the interpretation of significant findings: The role of mixed methods research. *The Qualitative Report*, 9(4) 770-792.
[32] Cohen, J. (1994) The Earth is Round (*p*<.05). *American Psychologist*, 49(12):997-1003.
[33] Cohen, J. (1992) Statistical Power Analysis. *Current Directions is Psychological Sciences*, 1(3): 98-101.
[34] Erdfelder, E., Faul, F., & Buchner, A. (1996). GPOWER: A general power analysis program. *Behavior Research Methods, Instruments, and Computers, 28*, 1-11. doi:10.3758/BF03203630

[35] Baguley, T. (2009). Standardized or simple effect size: What should be reported?. *British journal of psychology*, *100*(3), 603-617.
[36] Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* Hillsdale, NJ: Lawrence Erlbaum.
[37] Brenner, P. S., Serpe, R. T., & Stryker, S. (2014). The causal ordering of prominence and salience in Identity Theory: An empirical examination. *Social Psychology Quarterly*, *77*, 231-252.
[38] Jolliffe, I. T. (2002). *Principal components analysis*. New York, NY: Springer.
[39] Dunteman, G. H. (1989). *Principal components analysis* (Sage University Paper series on Quantitative Applications in the Social Sciences, Series No. 07-069). Newbury Park, CA: Sage.

[i] The survey administered in the second stage contained a screening question so that students who participated in the survey administered during the *a priori* power analysis were removed.