Constructing a Measure of Affect Towards Professional Practice: What matters for Engineers?

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Abstract *Identity, or how people choose to define themselves, is emerging as an explanation for who pursues and persists in engineering. Recent developments in the study of engineering identity, including studies of math and science identity, tend to emphasize the academic aspects of engineering without considering aspects of professional practice central to the development of an engineering identity. This paper outlines the methods used to create a new survey measure: affect toward elements of engineering practice. We followed the item generation, refinement, and instrument validation steps required for psychometric validation of a new survey measure. Through this process a final list of 34 items was administered in a survey in the fall of 2016 to engineering undergraduates. We conducted an exploratory factor analysis and established internal consistency using Cronbach's alpha on a subset of the data sample (n=384). The resulting factors reflect key elements of affect towards engineering professional practice.*

Background and Theoretical Framework

Identity is gaining in popularity as a lens for studying persistence in engineering. Much of this work is based on adaptation of identity studies in math and science (e.g., Godwin, 2016; Godwin, Potvin, Hazari, & Lock, 2013; Prybutok, Patrick, Borrego, Seepersad, & Kirisits, 2016). In math and science, identity as a predictor of choice and persistence in STEM fields is composed of recognition, performance/competence, and interest factors (Carlone & Johnson, 2007; Cass, Hazari, Cribbs, Sadler, & Sonnert, 2011; Chemers, Zurbriggen, Syed, Goza, & Bearman, 2011). While engineering has much in common with other STEM fields, engineering is unique because it is a profession defined by common practices and career paths (Downey, 2005). Prior work, which adapts math and science identity measures to engineering identity, has to date largely ignored professional practice aspects of engineering.

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The goal of the current work is to develop a measure of affect toward elements of professional engineering practice. We define elements of engineering practice as the skills and tasks that are involved in engineering work. Developing a measure of affect toward elements of engineering practice is important for several reasons. Research finds that when individuals develop affect for certain skills, methods, subject matter, or tools, they are more likely to engage in educational and professional pursuits that are consistent with their attitude towards the knowledge and skills composing that practice (e.g., Lopatto, 2004; Sheppard et al., 2010). Furthermore, affect for elements of engineering practice is likely to drive identification with the engineering profession. As more advanced students are exposed to engineering through formal and informal education, there are more opportunities to study how engineering identity develops over time as students are making decisions about engaging in authentic engineering experiences such as co-ops and internships. However, little emphasis has been placed on defining and measuring professional practice and its potential connection to identity and persistence. This gap in the literature presents a unique opportunity to make an important contribution by explicitly examining how students' affect towards key elements of engineering practice predicts their engineering identities. The first step towards narrowing this gap is establishing a measure of affect towards key elements of engineering practice. In a broader project, we seek to understand how an individual's affect toward elements of engineering practice, i.e., the extent to which one likes these elements, predicts their attraction to and retention in engineering education and the engineering profession, via its effects on identification with the engineering profession.

Two aspects of research are potentially relevant to this work: studies of professional activities and identity, and frameworks for defining engineering professional practice. Work in the area of the former has established that many activities related to the professional aspects of engineering positively impact engineering-related outcomes; those activities include building things, taking things apart, programing, playing computer games, being interested in how things work, or the impact of engineering projects and work experiences on career choice and persistence (e.g., Atman et al., 2010; Pierrakos, Beam, Watson, Thompson, & Anderson, 2010). Yet few studies directly measure engineering identity. Only one prior study focused on the professional aspects of engineering identity development in undergraduate students (Meyers, Ohland, Pawley, Sillman, & Smith, 2012), and found that design, teamwork and professional responsibility were most commonly associated by undergraduates with engineering. This study was inconclusive about how such elements predicted engineering identity.

Secondly, there are few existing frameworks for professional engineering practice that could inform the development of a measurement scale. In "Towards a theoretical framework for engineering practice," Trevelyan (2014) primarily argues that engineering work is more about technical coordination than applying math and science. Williams and Figueiredo (2014) reinforce this finding by listing frequencies of specific tasks completed by practicing engineers in Portugal. A lack of an effective tool to measure affect towards professional engineering practice with the eye towards measuring engineering identity motivated the work in this study.

Methods

Instrument Development

We followed the item generation, refinement, and instrument validation steps required for psychometric validation of a new survey measure (e.g., Hinkin, 1998) to create a new survey measure of individuals' affect toward elements of engineering practice.

Step 1. Item generation. We used an inductive method to generate survey items to assess affect towards elements of engineering practice, and we compared them to deductively derived items generated in parallel by two engineering members of the research team who were blind to the inductive process, as described below. Two members of the research team who were not involved in the inductive item generation (Seepersad and Kendall) created a list of items deductively based on ABET's EC2000 Criterion 3a-k as a theoretical basis for defining elements of engineering practice. There is precedent in other fields, including medical education (Crossley & Vivekananda-Schmidt, 2009) and teaching (Cheung, 2008) for using accreditation standards as a starting point for developing professional identity scales. The ABET EC2000 outcomes for engineering (ABET, 2012) were developed collaboratively between industry and engineering stakeholders through an extended, multi-year process (Prados, Peterson, & Lattuca, 2005).

Concurrently, Borrego conducted inductive interviews with 7 young alumni (3 women and 4 men) who graduated with bachelor's or master's degrees in mechanical, civil or biomedical engineering from LPI within the last 2-5 years, and Patrick and Choe conducted focus groups with 15 undergraduate students 5 graduate students in engineering, across the three disciplines at LPI.

The interview/focus group questions were:

1. Students: Let's form a working definition of an engineer. Alumni: What is your definition of an engineer?
2. What does it mean to think like an engineer?
3. What do engineers do?
4. What are the qualities of engineers?
5. What does it take to be successful in an engineering career?

We audio recorded all interviews and focus groups, and Choe and Patrick later coded them thematically. Prior to establishing semi-structured focus groups for the engineering students, these two authors conducted a pilot of the interview protocol with a group of graduate students with backgrounds in STEM teaching. We wanted to test the process of asking questions and summarizing responses on whiteboards in conjunction with audio recording. The parallel process allowed us to listen to the recordings and see the development of the written artifact through photographs because we used different dry erase marker colors for each question. Patrick and Choe independently coded both the focus group data and the summary notes from the alumni interviews. They then met to create one combined list. Alumni responses were particularly helpful in developing specific item wording. We combined both the inductively and deductively derived item lists to generate a master list of 96 items.

Step 2. Content validity assessment. The initial master list of scale items was content validated using two methods. First, we established face validity by circulating the list of items to a set of experts. Modifications to the list were made based on their feedback. Next, we used the procedure for substantive validity assessment developed by Anderson and Gerbing (1991), whereby we administered a survey to 5 researchers with relevant expertise. Each researcher rated the item and included any written feedback on the extent to which each response assigns an item to the intended construct.

Step 3. Initial item reduction. Using the rule of thumb of an item-to-respondent ratio of 1:10, we administered the final set of 34 items derived from Step 2 in a survey to the target population along with other constructs. We conducted all data analyses using StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP. With a sub-sample, we conducted an exploratory factor analysis (EFA) to determine the sub-dimensions of our new measure of affect toward elements of engineering practice. As we expected the factors to be correlated, we used principal axis factoring, with a promax rotation to extract factors. We retained factors and items based on both theory and quantitative checks. We used a scree plot to determine the number of factors to extract in the exploratory factor analysis. However, this method is subjective, at times producing inconclusive results. Using the scree plot we identified an approximate range of factors to be extracted as 5-8. Subsequently we conducted analyses that forced the extraction of this range of factor solutions to determine the structure that best fit with the data. We examined the final factors for internal consistency using Cronbach's alpha.

Instrument Administration and Participants

The target population for this study was architectural engineering, civil engineering, mechanical engineering (ME), and biomedical engineering (BME) undergraduate majors. We administered surveys to a cross-section of engineering students at two institutions. We secured IRB (ethics) clearance at both study institutions. We refer to these institutions as LPI and HSI, respectively. LPI is a large public institution in the U.S. with high-ranking engineering programs where the students are admitted directly into specific majors (there is no general or freshman engineering program). Specific to LPI, architectural and civil engineering students are in the same department and share many required courses; for this analysis they were grouped together (collectively labeled CE). HSI offered a unique opportunity to survey students from an institution with a much more open enrollment policy and a predominantly Hispanic population (80%), with many students who commute to school daily. Unlike LPI, HSI does have a first year pre-engineering program. Therefore, HSI survey participants included students from the mechanical engineering department as well as pre-engineering students enrolled in first year mechanical engineering courses. At both institutions, freshmen, sophomores, juniors, and seniors were surveyed.

We administered the survey, which took approximately fifteen minutes to complete, in class electronically during the second week of the fall 2016 semester in a total of 22 engineering courses. Students with more than one major were retained in the analysis as long as one major was CE, ME, or BME. A total of 1465 participants consented to the survey; we only examined responses with complete data on affect towards professional practice items. The response rate was approximately 70%. The sample demographics were approximately 66% male and 34% female. Based on first semester of enrollment, 27.6% were freshmen, 27.1% were sophomores, 18.8% were juniors, and 25.8% were seniors across the two institutions. We took a random sample of n=384 for our analytical sample.

Results

It was clear during the initial coding process that the items generated in the focus groups and interviews mirrored many of the ABET criteria. Table 1 lists a sample of preliminary items and themes.

Table 1: Sample of preliminary items and themes from Step 1. Item Generation

Item	**Theme**
Innovation	Professional Skills
Networking	
Curiosity	
Efficiency	Design related activities
Planning	
Designing with constraints	
Building stuff	Attributes of Engineering

Collaboration	
Applying math and science knowledge and skills	
“Getting people to do things”	Teamwork Practices
Working with multidisciplinary teams	
Explaining technical content to “other people without engineering backgrounds”	

Exploratory Factor Analysis

We determined that the 6-factor solution best fit the data and theory. Table 1 presents the results of exploratory factor analysis (EFA) of this solution. We retained nearly all items, 30 of the 34 items hypothesized to characterize affect towards professional practice, in the final EFA. We compared all items to the minimum item communalities of 0.40 and threshold loading of 0.32 to determine future item trimming (Osborne & Costello, 2009). We removed problematic items based on these criteria. In the final analysis, “Communicating visually, for example using drawings or prototypes” continually caused severe cross-loadings of other items in the analysis; removal of this item resulted in a much cleaner factor structure. A set of 5 other items – c, d, h, n, and ee – also had potentially problematic cross-loadings (items at the minimum threshold or items with loadings less than .15 difference from the main loading). Each of these items consistently split on 2 factors in our analyses. However, we retained these items in the analysis as they strengthened the resulting overall factor structure. Three other items, “generating creative solutions to challenging problems”, “knowing how to teach myself something if I have to”, and “analyzing problems to identify their root causes” did not load onto any factor. We ultimately named the newly constructed factors as follows: framing and solving problems, design, project management, analysis, collaboration, and tinkering. The factor loading and internal consistency for retained factors are listed in Table 2.

Table 2: Retained Factors of Affect Towards Engineering Professional Practice

Latent Construct	Item	Factor Loading	Unique Variance
Framing and Solving Problems (α = 0.83)	(a) Solving problems that allow me to help a lot of people	0.58	0.66
	(b) Learning new things from other people I’m working with	0.76	0.44
	(d) Finding a better way of doing something	0.41	0.42
	(f) Continually learning new things	0.63	0.45
	(o) Using my skills and knowledge to address societal problems	0.39	0.56
	(p) Applying my science knowledge and skills	0.41	0.49
	(r) Being curious	0.42	0.54
Design (α = 0.86)	(k) Keeping up with contemporary issues involving technology	0.40	0.59
	(q) Identifying technical solutions that are as simple as possible	0.40	0.50

	(s) Designing and conducting experiments to test an idea	0.55	0.55
	(y) Searching for innovative ways to do things	0.38	0.50
	(v) Improving a design to make it more efficient (faster, better, cheaper)	0.46	0.47
	(z) Using technology to solve environmental problems	0.41	0.68
	(aa) Creating prototypes to test an idea	0.78	0.36
	(cc) Designing a system, a part/component of a system, or a process based on realistic constraints	0.68	0.45
Project Management (α = 0.72)	(l) Planning a project and staying organized to complete it	0.64	0.51
	(m) Using facts and information, instead of opinions, to make decisions	0.45	0.55
	(x) Tracking various aspects of a project to ensure that it stays on track	0.36	0.73
	(bb) Seeing a project through to its end	0.45	0.54
Analysis (α = 0.76)	(u) Applying my math knowledge and skills	0.56	0.47
	(gg) Using calculations and equations to evaluate things	0.68	0.42
	(hh) Identifying what I need to know to solve a problem or complete a project	0.50	0.46
Collaboration (α = 0.79)	(e) Presenting my work to others	0.46	0.55
	(n) Working with people with different skills and interests	0.40	0.54
	(t) Communicating verbally, for example in discussion with others	0.60	0.45
	(dd) Convincing others to accept my ideas	0.42	0.68
	(ee) Breaking a complicated problem into smaller parts	0.35	0.42
	(ff) Working collaboratively in teams	0.64	0.49
Tinkering (α = 0.75)	(c) Taking something apart to see how it works	0.50	0.41
	(h) Fixing things	0.57	0.49

To examine our assumption of the correlation between factors, we calculated Pearson's correlations between each of the retained factors. This correlation matrix reflects significant ($p \leq 0.001$) moderate to large relationships across nearly all the factors. The weakest correlations were between tinkering and project management (0.23) and tinkering and collaboration (0.29). Design shared correlations of 0.60, 0.63, 0.68 between tinkering, analysis, and framing and solving problems. These high correlations reflect the problems we saw in cross-loadings in the EFA. All other correlations ranged from 0.40 to 0.58.

Discussion

Facilitating the focus groups using white boards as well as recordings proved to be an effective means to conduct the interviews. While most focus group/interview protocols only allow the researcher to see the artifacts of the discussion, our methodology allowed the focus group participants to see artifacts of the discussion as they emerged. This allowed for immediate member checking between the participants and the researchers. Oftentimes students were able to clarify the meaning of their responses in real time and make connections between points of discussion. This technique often drew out more detailed information from the participants, particularly for the focus groups of 5 or more participants.

The goal of this study was to generate a new scale for measuring affect towards engineering professional practice. While not all items were ultimately retained from the item generation process in the factor analysis, the subsequent validity steps yielded a robust set of factors. Careful examination of the factors at the item level reveals characteristics of each latent variable. Surprisingly the factors did not align with either our *a priori* assumptions or with the ABET criteria. Clearly, ABET criteria influence our thinking about engineering. Yet the resulting factor structure reflects a more nuanced interpretation of the ABET criteria based on students' attitudes. While some criteria (e.g., ethics) were not retained in the final set, the overall structure suggests yet another way to consider the revision of these criteria currently underway.

Despite a few cross-loadings, mainly due to ambiguity in the wording of the items, the results of this study are very promising. The key elements that compose affect towards engineering practice – framing and solving problems, design, project management, analysis, collaboration, and tinkering – collectively captured the practices we intended to measure. Tinkering is perhaps the most intriguing. "Taking something apart to see how it works" and "fixing things" are often questions used in the studies of engineering identity. While this was only a two-item factor in our study, it would be worth adding items to the factor to see if tinkering is a distinct professional practice or simply a common activity among those interested in engineering as a whole.

The most cohesive factor in our results was collaboration. Students in this study seem to associate teamwork with communication skills. This is not surprising as teamwork and communication skills are often emphasized together in capstone design, and successful teamwork often entails effective communication. Another notable result was the separation of "applying math knowledge" versus "applying science knowledge" into two factors. Math loaded on the analysis factor whereas science loaded on framing and solving problems. Perhaps the emphasis on a prescribed method in schooling led students to associate science knowledge with framing and solving problems, and math knowledge with analysis. The most indistinguishable factors during the item generation process were problem solving (renamed framing and solving problems) and design. At several points we considered collapsing these items on a theoretical basis. Criterion I, "a recognition of the need for, and an ability to engage in life-long learning," spanned the two factors: framing and solving problems and design. A set of ABET criteria: a. "an ability to design and conduct experiments, as well as to analyze and interpret data," c. "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" and e. "an ability to identify, formulate, and solve engineering problems" also spanned these two factors. Of this set of criteria, c. is arguably the densest in terms of content. Critical to engineering professional practice, both these factors accounted for nearly half of all the items included in our scale. Clearly the emphasis on these practices has not gone unnoticed among undergraduate students.

To be clear, this study was measuring affect towards engineering professional practice, not professional identity or engineering identity. Affect can best be thought as an affinity towards or liking, whereas identity is seeing oneself as or being recognized as a particular type of person. There are similarities between affect and identity, however it was necessary to distinguish this two constructs to investigate the difference between liking a particular practice versus being a particular type of person.

Conclusion

In sum, this work illustrates a new dimension of measuring attitudes related to professional practices in engineering. The factors derived from this study are intended to be a first step in creating a robust scale of affect towards engineering professional practice. We have described the step-by-step development of items based on qualitative studies, theory, and criteria of the discipline. These steps are essential to the validation process discussed in this paper. By first gaining an understanding of key elements of engineering practice, we can then make more refined changes to our measures of affect towards engineering professional practice, identity, and other engineering related outcomes such as persistence. Richer descriptions and measures of student experience are needed as we as engineering educators seek to further illuminate a path from affect towards engineering professional practice to full participation in the engineering profession and community.

Implications and Future Work

This study explored the key elements of affect towards the engineering profession.
In future work, using the remaining data from this sample, we will conduct a confirmatory factor analysis on the reduced set of items resulting from EFA, and assess the final factor structure using various goodness of fit indices. As part of a larger longitudinal study, we will continue to survey students from over 100 high schools, plus university freshmen, sophomores, juniors, seniors, master’s and doctoral students. The broader goal of that study is to model engineering identity and persistence based on these and other newly constructed factors from our research. This work has important implications for prospective engineering students, undergraduate students, graduate students, and professionals in engineering settings. In conjunction with qualitative data from a purposeful sample of alumni participants, which provides a richer description of attitudes and experiences, we can further characterize what factors contribute to students’ decisions to major and persist in engineering. Addressing the professional aspects of engineering is essential to furthering the work on engineering identity.

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