A Measure of Affect towards Key Elements of Engineering Professional Practice

Identity, or how people choose to define themselves, is emerging as an attractive explanation for who persists in engineering. Many studies of engineering identity build off of prior work in math and science identity, emphasizing the academic aspects of engineering. However, affect towards professional practice is also central to engineering identity development. This paper describes the methods used to create a new survey measure of individuals' 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. We generated items deductively using the literature on engineering professional skills and practice and inductively based on interviews with practicing engineers, engineering graduate students, and engineering undergraduate students. We blended the inductively and deductively derived item lists to create a list of initial items for the measure. We circulated this list of items to a set of engineering and professional identity experts to establish face validity and made modifications based on their feedback. The final list included 34 items. These 34 items were administered in a questionnaire survey in the fall of 2016 to 1465 engineering undergraduates in three majors at two institutions. We conducted an exploratory factor analysis (EFA) and established internal consistency using Cronbach's alpha on a subset of the analytical sample data (n=384). The resulting factors fit our a priori assumption of the factors theorized to characterize affect towards engineering professional practice. Using the remaining data (n=904), we conducted a confirmatory factor analysis on the reduced set of items resulting from EFA. The results indicate an emergent factor structure for affect towards elements of engineering practice.

Introduction

Attracting diverse students to engineering education and retaining them in the engineering profession is important to national competitiveness (Century, 2007). Identity, or how people choose to define themselves (Gee, 2000), is emerging as an attractive explanation for who persists in engineering. Researchers have examined a wide range of factors that explain persistence in engineering education and the engineering profession, including perception/knowledge of the profession, subject matter ability, and engagement in engineering related activities (Burtner, 2005; Mau, 2003; Pierrakos, Beam, Constantz, Johri, & Anderson, 2009). While some studies have investigated relationships between math and science identities on choice of an engineering major (e.g., Godwin, Potvin, Hazari, & Lock, 2013), very few studies focus on identity as it relates to engineering as a profession. At present, there is little empirical evidence to support the hypothesized factors that relate to affect towards professional practice. In math and science, identity -- as composed of recognition, performance/competence, and interest factors -- is used as a predictor of choice and persistence in STEM fields (Carlone & Johnson, 2007; Cass, Hazari, Cribbs, Sadler, & Sonnert, 2011; Chemers, Zurbriggen, Syed, Goza, & Bearman, 2011). In engineering, there is a dearth of literature using these aforementioned factors as they relate to professional practice. The majority of studies in engineering have utilized

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math, science, and physics identity factors to predict identity. Only recently have identity factors been developed to specifically measure engineering identity (Godwin, 2016; Prybutok, Patrick, Borrego, Seepersad, & Kirisits, 2016).

One key explanation that has not been tested to date is the influence of affect toward elements of engineering practice, which are the skills and tasks that are involved in engineering work. ABET has used a set of elements of engineering practice to assess engineering schools' educational processes and outcomes. Although these criteria may soon be revised to a shorter list, these 11 criteria have been in wide use for over 15 years and constitute an appropriate starting point for developing a comprehensive measure of affect toward elements of engineering practice. 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. 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 measuring professional practice and its potential connection to identity and persistence. Engaging in professional practice is central to the formation of engineers but is not addressed in studies focusing on math and science identity. This gap in the literature presents a unique opportunity to make an important contribution to the literature by explicitly examining how students' affect towards key elements of engineering practice predict 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 within engineering education and the engineering profession, via its effects on identification with the engineering profession.

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 present in both affect and identity, namely students' attitudes towards their ability to organize and execute given types of performances in engineering referred to as performance/competence in identity work. Therefore some of the factors currently used to measure identity may be applicable to measuring affect towards professional engineering practice. However, this does not minimize the importance of measuring and refining scales to explicitly measure affect.

Literature Review

Engineering is a profession as well as a set of academic disciplines. Engineering students are trained to enter a specific profession defined by common practices and career paths (Downey, 2005) which may vary widely but are nonetheless more well-defined than in any other STEM discipline. Engaging in professional practice is central to the formation of engineers, whether it takes place in formal classrooms, maker spaces, extra- and co-curricular activities, co-ops and internships, or other mentored or team experiences (National Science Foundation, 2015). Key aspects of engineering such as design, ethics and professional responsibility, teamwork and global context are simply not addressed in engineering identity studies focusing on math and science (e.g., Godwin et al., 2013).

Prior work 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, or just being interested in how things work (Pierrakos, Beam, Watson, Thompson, & Anderson, 2010). For example, some of these activities (including playing games like Tetris) are particularly helpful in the development of 3-D spatial skills, which are important for engineers (Cherney, 2008; Sorby, 2009). This literature has not often studied engineering identity as an outcome; one exception is a study by Sheppard et al. (2010) which found that affect toward building and determining how things work predicted engineering identity in undergraduates.

While some prior studies have investigated the impact of engineering projects and work experiences on career choice and persistence (e.g., Atman et al., 2010), the lack of studies directly measuring engineering identity limits our ability to link these experiences to the professional formation of engineers. Only one prior study focused on the professional aspects of engineering identity development in undergraduate students at a single institution (Meyers, Ohland, Pawley, Sillman, & Smith, 2012), and found that design, teamwork and professional responsibility were most commonly associated by undergraduates with engineering. Yet this study was inconclusive about how such elements predicted engineering identity. 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.

There are a few existing frameworks for professional engineering practice that could inform 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. However, 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 were developed collaboratively between industry and engineering stakeholders through an extended, multi-year process (Prados, Peterson, & Lattuca, 2005). As described below, we consulted ABET criteria and proposed revisions as one part of our scale development process, complemented by interviews with practicing engineers and engineering students.

Methods

Instrument Administration and Participants

The target population for this study was architectural engineering, civil engineering, mechanical engineering (ME), or biomedical engineering (BME) undergraduate majors. Surveys were administered to a strategic selection of engineering students at two institutions. For the purposes of this study 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). Survey participants included students from the Civil, Biomedical, and Mechanical Engineering departments. Civil and Mechanical are two of the largest, traditional engineering disciplines but enroll quite different gender and ethnic cross-sections. At 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). Biomedical engineering is a much newer department with a higher representation of female students and a larger population of students who choose non-engineering career tracks (e.g., medical school, professional school). HSI offered a unique opportunity to survey students from an institution with a much more open enrollment policy and a predominantly Hispanic population (80%), many of whom commute to school daily. Unlike the LPI, this institution does have a first year pre-engineering program. Therefore, 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.

The survey, which took approximately fifteen minutes to complete, was administered in class electronically during the second week of the fall 2016 semester in a total of 22 engineering courses: 6 civil engineering (CE) courses, 3 architectural engineering (AE) courses, 8 mechanical engineering (ME) courses, and 5 biomedical engineering (BME) courses. Of the courses in which the survey was administered, 12 were designated by the institution as lower-division (freshman and sophomore level) and 10 were upper-division (junior and senior level).

Students with more than one major were retained in the analysis as long as one major was CE, ME, or BME. Non-CE, non-ME, and non-BME students were removed from the data set. 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%. We took a random sample of n=384 for our analytical sample. The sample was approximately 66% male and 36% 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.

Instrument Development

To create a new survey measure of individuals' 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 (e.g., Hinkin, 1998). In addition to authentic engineering practices, we used ABET's EC2000 Criterion 3a-k as a theoretical basis for defining elements of engineering practice:

a. an ability to apply knowledge of mathematics, science, and engineering
b. 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
d. an ability to function on multi-disciplinary teams
e. an ability to identify, formulate, and solve engineering problems
f. an understanding of professional and ethical responsibility
g. an ability to communicate effectively
h. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i. a recognition of the need for, and an ability to engage in life-long learning
j. a knowledge of contemporary issues
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (ABET, 2012)

Although these criteria may soon be revised to a shorter list, these 11 criteria have been in wide use for over 15 years and constitute an appropriate starting point for developing a comprehensive measure of the elements of engineering practice. We will consider new wording of the proposed ABET revisions in our scale development, e.g. "analysis and synthesis" in engineering design, "appropriate experimentation and testing procedures," "analyze and draw conclusions from data," communicating with "a range of audiences through various media," and language around project management and teamwork including "manage risk and uncertainty" (Flaherty, 2015).

Step 1. Item generation. We used an inductive method to generate survey items to assess affect toward the 11 elements of engineering practice, and we compared them to deductively-derived items generated in parallel by an engineering member of the research team who is blind to the inductive process, as described below. We used the extant definitions of the elements of engineering practice, and the literature that has examined them in prior research. Using this background, we 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 the institution within the last 2-5 years, and focus groups with 15 undergraduate students 5 graduate students in engineering, across the three disciplines, to (i) identify the content domain of affect toward the elements of engineering practice, and (ii) generate a list of potential survey items to measure them. We grouped the responses thematically and then used the participants' specific language whenever possible to generate items. 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?

Concurrently, two members of the research team who were not involved in the inductive item generation created a list of items deductively, based on the description and measurement of the elements of engineering practice in the literature. We compared the inductively and deductively derived item lists and blended the two to create a master list of initial items for the measure.

Step 2. Content validity assessment. The initial list of scale items for measuring affect toward the 11 elements of engineering practice was content validated using two methods. First, we circulated the list of items to a set of experts to establish face validity and made modifications based on their feedback. Next, we used the procedure for substantive validity assessment developed by Anderson and Gerbing (1991), whereby we administered a survey including the set of items along with items for 2-3 other constructs to 5 researchers with relevant expertise and asked respondents to indicate how well each item measures each of the constructs; content validity was assessed based on the proportion of respondents who assign items to the intended construct and the extent to which each respondent assigns an item to the intended construct.

Step 3. Initial item reduction. The final set of items derived from Step 2 was administered in a survey to the target population (using the rule of thumb of an items: respondents ratio of 1:10) along with other constructs. All data analyses were conducted using StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP. We used a sub- sample (n=384) to conduct an exploratory factor analysis to determine the sub-dimensions of our new measure of affect toward elements of engineering practice. We used principal axis factoring to extract factors, with a promax rotation, given that we expected the factors to be correlated., Factors and items were retained based on both theory and the data, balancing rigor and parsimony in coverage of the construct.

A scree plot was used to determine the number of factors to extract in the exploratory factor analysis. This method is subjective, at times not producing conclusive results. In keeping with standard practice, once the likely number of factors was determined based on the theory and the scree plot, we also conducted analyses that forced the extraction of one fewer factors and one more factors, to examine whether the factor structure that was determined was indeed the best fit with the data. The resulting factors of affect toward elements of engineering practice were examined for internal consistency using Cronbach's alpha. A table of the final items and question stem are listed in the appendix,

Step 4. Confirmatory factory analysis. We conducted a confirmatory factor analysis on the reduced set of items resulting from Step 3 by conducting structural equation modeling (e.g., Kline, 2015) on a holdout sub-sample from Fall 2016 which is not included in the exploratory factor analysis. Using the item variance-covariance matrix from this holdout sample, we examined the goodness of fit of the factor structure using the following indices: Chi-square, Comparative Fit Index (CFI), Tuck Lewis Index (TLI), and the root mean square error of approximation (RMSEA). We also examined modification indices for each of the survey items to identify potential cross-loadings and trim the list of items if necessary. After re-testing the goodness of fit following the trimming of items, the resulting final version of affect towards elements of engineering practice were examined for internal consistency using Cronbach's alpha.

Results

Exploratory Factor Analysis

Table 1 presents the results of exploratory factor analysis of the 6-factor solution. We ultimately decided to constrain the 6-factor solution as it best captured the trends seen in the preliminary analyses of the other factor solutions. Of the 34 items hypothesized to characterize affect towards professional practice, 30 items were retained in the final EFA. We named these newly constructed factors as follows: framing and solving problems, design, project management, analysis, collaboration, and tinkering. All items were compared to the minimum item communalities of 0.40 and threshold loading of 0.32 to determine future item trimming (Osborne & Costello, 2009). Through several iterations "Communicating visually, for example using drawings or prototypes" continually caused severe cross-loadings of other items in the analysis. The removal of the item resulted in a much cleaner factor structure. This item was likely problematic due to its multifaceted nature. While this item was intended to measure visual communication, it likely caused problems in our analysis because it also addressed notions of design. 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.

Although not included in Table 1, we encountered 5 items – c, d, h, n, ee – with potentially problematic cross-loadings (loadings of double the main loading). These items consistently split on 2 factors in our analyses. Namely c and h cross-loaded onto design; d cross-loaded onto tinkering; n cross-loaded onto framing and solving problems; and ee cross-loaded onto analysis. Despite these problematic loadings we felt these items needed to remain in the analysis because of their theoretical relevance to the respective factors. The factor loading and internal consistency for each of these factors are listed in Table 1.

Table 1 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
	(x) Tracking various aspects of a project to ensure that it stays on track	0.36	0.73
	(m) Using facts and information, instead of opinions, to make decisions	0.45	0.55
	(bb) Seeing a project though 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	(e) Presenting my work to others	0.46	0.55

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(α = 0.79)	(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

The correlation matrix (Table 2) of the retained factors shows moderate to large relationships across nearly all the factors. All correlations are significant at the $p \leq 0.001$ level. The weakest relationships are between Tinkering and Project Management, and Collaboration. The most correlated factors reflect the problems we saw in the cross loading from the EFA. Namely Design shares a correlation of 0.60 or higher with three factors in the model.

Table 2 Pearson's correlation matrix of retained factors from EFA

Factor	1)	2)	3)	4)	5)	6)
1) Framing and Solving Problems	-					
2) Design	0.68	-				
3) Project Management	0.56	0.53	-			
4) Analysis	0.53	0.63	0.55	-		
5) Collaboration	0.60	0.53	0.58	0.49	-	
6) Tinkering	0.40	0.60	0.23	0.40	0.29	-

All significant at the $p \leq 0.001$ level

Confirmatory Factor Analysis

We conducted a confirmatory factor analysis in order to validate the underlying structure of our scale based on information gathered from the EFA and our knowledge of the theorized latent constructs. The structure of the CFA is researcher specified; therefore it gives us more flexibility in testing the relations between the observed variables and the latent variables including covariances between items. Using the factors identified in the EFA we fit a model containing the 6-factor solution. To assess a better fitting model we returned to the EFA to investigate problematic cross-loaders and questions that seemed to be out of place. In doing so we identified items k, o, c, and h are candidates for removal. Note the construct of tinkering was completely removed in the process of this analysis in support of a better fitting model. Construct reliability for the theorized constructs was 0.86 for design, 0.74 for project management, 0.83 for framing and solving problems, 0.77 for analysis, and 0.80 for collaboration.

To further assess the validity of the model, we added other constructs that are theorized to relate to affect towards professional practice to further prove discriminant validity between factors. We added performance/competence in engineering ($\alpha = 0.88$) and a new measure of professional identity ($\alpha = 0.84$). Both constructs were identified as suitable candidates based on their moderate correlations with the other latent constructs and theory. We allowed these constructs to vary freely in our model. In addition we used modification indices to further improve model fit. The majority of the covariance between error terms came between framing and problem solving, design, and collaboration. The model fit indices were at an acceptable level (RMSEA = 0.052, CFI = 0.920, TFI = 0.909, and $X^2 = 1679.94$; df= 494; p= 0.000). In considering the high correlations between the latent factors, the results of the confirmatory factor analysis indicate the latent factors may be related to a higher order construct of affect toward elements of engineering practice. Table 3 shows the correlations between the latent factors. All latent factors should be further tested and modified to establish discriminant validity.

Table 3 Correlations among latent factors in confirmatory factor analysis

Factor	1)	2)	3)	4)	5)	6)	7)
1) Framing and Solving Problems	-						
2) Design	0.85	-					
3) Project Management	0.85	0.82	-				
4) Analysis	0.81	0.84	0.89	-			
5) Collaboration	0.81	0.75	0.91	0.85	-		
6) Identification with Professional Practice	0.43	0.49	0.36	0.46	0.34	-	
7) Performance/ Competence in Engineering	0.50	0.46	0.44	0.46	0.39	0.45	-

All significant at the $p<0.004$ level

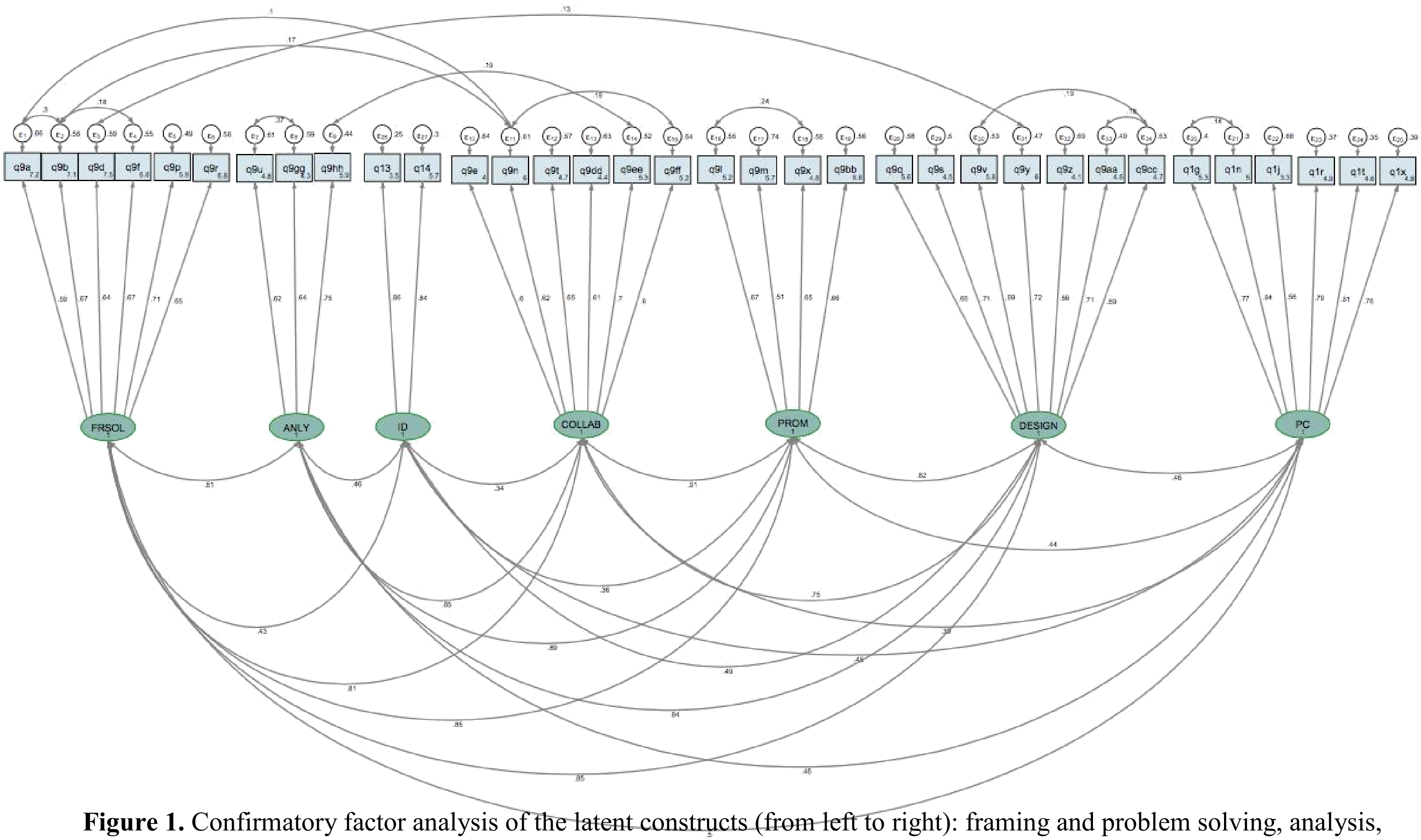

Figure 1. Confirmatory factor analysis of the latent constructs (from left to right): framing and problem solving, analysis, identification with professional practice, collaboration, project management, design, and performance/competence in engineering.

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Discussion

This study generated a new scale for measuring affect towards engineering professional practice. Surprisingly the factors did not align as predicted by our assumptions. Furthermore, the newly constructed affect towards engineering professional practice factors align only in part with the *content* of the ABET criteria. Our resulting factor structure specifically reflects a more nuanced interpretation of the ABET criteria based on students' attitudes. One reason for this result is the complexity of the ABET criteria, which seem to be distilled into a more compact representation in the scale presented here. Secondly the inclusion of additional items derived from the item generation process may have contributed to a disruption in a factor structure based only ABET items. 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.

The most cohesive factor in our results was collaboration. Even in the preliminary steps of assessing the proper factor solutions, the items composing collaboration consistently grouped together. 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 undergraduate engineering curricula, and successful teamwork often entails effective communication. Another notable result was the separation of "applying math knowledge" versus "applying science knowledge" into two factors. The former loaded on analysis whereas the latter loaded on framing and solving problems. Perhaps the emphasis on a prescribed method, such as the scientific method, throughout the students' academic backgrounds led them to associate science knowledge with framing and solving problems. A similar indoctrination into practice may also explain why applying math knowledge and skills loaded on analysis in comparison to other factors such as framing and solving problems or design. Project management was also a stable factor when item (g) was removed from the model. As previously mentioned, the complexity of this item likely caused other items to load inconsistently. The emergence of project management as a stand along factor is unique in that skills related to project management are not outlined in the ABET criteria.

Returning to the ABET criteria, we noticed several points of discussion. Particularly in the process of naming the factors, the items that composed the factors did not always reflect how we tend to discuss characteristics of engineering professional practice. The most indistinguishable factors during the item generation process were problem solving and design. At several points we considered collapsing these items on a theoretical basis. However, we decided to let these factors stand alone as independent constructs. The main criteria that contributed to this discussion were 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." Of these three criteria, c. is arguably the densest in terms of content. Our results indicate students' attitudes relating to this criterion cut across the factors of framing and solving problems and design. Similarly, criteria i. "a recognition of the need for, and an ability to engage in life-long learning" spanned the same two factors. One item, 9w (see Appendix), we constructed to measure continual life-long learning did not load in our final analysis. 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 at the collegiate or professional level.

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. The last factor 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.

Future Work and Conclusion

This study explored the key elements of affect towards the engineering profession. As part of a larger longitudinal study, we will continue to survey students from over 100 high schools, plus university freshmen, sophomores, juniors, seniors, masters and doctoral students. The broader goal of that study design is to model engineering identity and persistence based on these newly constructed factors. In conjunction with qualitative data from a purposeful sample of alumni participants, which provide 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.

The study has important implications for perspective engineering students, undergraduate students, graduate students, and professionals in engineering setting. Future work will better inform our understanding of the connection, if any, between affect, identity, and observed persistence. To this end we plan to further refine our identity framework by including content-specific identity, professional identity, personal identity, and social identity across contexts and backgrounds including race, gender, major, and campus culture. Truly intersectional work on engineering identity and persistence is a distinct direction for future work as these identities and backgrounds have yet to be substantially considered in the study of engineering identity and persistence.

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 engineer profession and community.

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Appendix

Table 4 List of final items based on item generation and a priori assumptions

Survey Item	Survey Wording	A Priori Dimension	Final Dimension
9a	Solving problems that allow me to help a lot of people	Problem solving	Framing and problem solving
9b	Learning new things from other people I'm working with	Problem solving	Framing and problem solving
9c	Taking something apart to see how it works	Design	r.f.m
9d	Finding a better way of doing something	Problem solving	Framing and problem solving
9e	Presenting my work to others	Communication	Collaboration
9f	Continually learning new things	Continually learning	Framing and problem solving
9g	Communicating visually, for example using drawings or prototypes	Communication	r.f.m
9h	Fixing things	Motivation	r.f.m
9i	Analyzing problems to identify their root causes	Analytical skill	n.l.
9j	Generating creative solutions to challenging problems	Problem solving	n.l.
9k	Keeping up with contemporary issues involving technology	Continually learning	r.f.m
9l	Planning a project and staying organized to complete it	Project management	Project management
9m	Using facts and information, instead of opinions, to make decisions	Problem solving	Project management
9n	Working with people with different skills and interests	Team work	Collaboration
9o	Using my skills and knowledge to address societal problems	Motivation	r.f.m
9p	Applying my science knowledge and skills	Other	Framing and problem solving
9q	Identifying technical solutions that are as simple as possible	Design	Design
9r	Being curious	Motivation	Framing and problem solving

9s	Designing and conducting experiments to test an idea	Analytical skill	Design
9t	Communicating verbally, for example in discussion with others	Communication	Collaboration
9u	Applying my math knowledge and skills	Other	Analysis
9v	Improving a design to make it more efficient (faster, better, cheaper)	Design	Design
9w	Knowing how to teach myself something if I have to	Continually learning	n.l.
9x	Tracking various aspects of a project to ensure that it stays on track	Project management	Project management
9y	Searching for innovative ways to do things	Design	Design
9z	Using technology to solve environmental problems	Social consciousness	Design
9aa	Creating prototypes to test an idea	Design	Design
9bb	Seeing a project through to its end	Motivation	Project management
9cc	Designing a system, a part/component of a system, or a process based on realistic constraints	Design	Design
9dd	Convincing others to accept my ideas	Communication	Collaboration
9ee	Breaking a complicated problem into smaller parts	Analytical skill	Collaboration
9ff	Working collaboratively in teams	Team work	Collaboration
9gg	Using calculations and equations to evaluate things	Design	Analysis
9hh	Identifying what I need to know to solve a problem or complete a project	Analytical skill	Analysis

r.f.m. (removed from CFA during model trimming); n.l. (Did not load in EFA) Question stem: As you think about your future after you finish your education, to what extent would you enjoy a profession or career that usually requires each of the following?