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Creating an Instrument to Assess the Professional Formation of Engineering Students at The College of New Jersey (TCNJ)

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Introduction

The School of Engineering at The College of New Jersey (TCNJ) has embarked on significant curricular change to support students in developing skills for and robust identities as pre-professional and professional engineers, in order to increase persistence and diversify the graduating cohorts. The curriculum draws on TCNJ's context as a primarily undergraduate institution (PUI) with a strong liberal arts focus to broaden and deepen students' intellectual engagement. In interviews, students report they chose TCNJ because of the small class sizes (typically between 22 -28 students) and close contact with faculty such a setting affords.

TCNJ is an ideal venue to study the professional formation of engineers, as this project couples a rich assortment of cross-curricular interventions related to professional formation activities with an interdisciplinary research team. TCNJ's engineering curricula prepare students for professional formation and workplace learning; elements include a liberal arts education, a co-curricular sequence, and widespread internship and research experiences. Specific co-curricular and extracurricular interactions that are particular strengths in the TCNJ engineering curricula include: engineering-specific ethics lessons/case studies, lessons on professional licensure, interaction with alumni through a formal mentoring program, preparing for, taking, and results of the FE Exam, teaming experiences focused on solving open-ended engineering design problems, internship and/or undergraduate research experiences, attendance at technical seminars, career preparation including résumé preparation at various stages of undergraduate study, and level of involvement in a professional engineering organization or an organization, related to affinity groups (e.g., IEEE, ASME, ASCE, BMES, SAE, SWE, NSBE, TCNJ, Humanitarian Engineering, Robotics). Studying the relevance of these interventions to the professional formation of engineers has the strong potential to provide insight into the effectiveness of TCNJ's comprehensive approach.

Research has been conducted to understand the impact of various curricular innovations, engineering identity, and inclusivity for historically underrepresented groups (such as women, low income students, and men of color) on engineering persistence (Cech 2015; Foor & Walden 2009; Nadelson 2014; Pierrakos et al 2009). To better understand the professional formation of engineers at PUIs, and better assess our curriculum within its liberal arts context, faculty from the School of Engineering partnered with two sociologists to develop an instrument to assess the professional formation of our students. The team was awarded an NSF grant to support this development (Sepahpour et al 2016).

The team settled on a survey instrument due to this method's strengths: ability to see a snapshot of a larger population, comparability across timepoints and institutions, and relative low resource intensity to conduct. Because identity development and professionalization happen over time, we aimed to capture student data at several points: first year, juniors/seniors, and new/long-time alumni. In accordance with best practice, we use iterative design drawing on initial qualitative interviews with each of these groups. Qualitative interviews allow researchers to explore topics in depth in order to discover previously unknown factors. Thus, these interviews were important to understand factors pertinent to TCNJ's environment and student body. In the first grant year, we developed and validated an instrument appropriate for first year students. In the second grant year, we will develop and validate versions tailored to juniors/seniors and to alumni. In future research, we will use these instruments to assess our curriculum and aim to partner with other institutions to conduct comparative research in order to further specify the contribution of the PUI context.

Developing the First-Year Instrument

Prior to creating the survey instrument, we conducted face-to-face semi-structured interviews with students in their first semester as engineering students. Interviews generally took place on campus outside of the engineering building. All interviews were electronically recorded and professionally transcribed; interviews lasted from about a half hour to an hour. Respondents were selected through a purposive sample design, with 16 students identified by School of Engineering faculty as potential respondents, with an even number of: white/Asian males, white/Asian females, black/Latino males, black/Latina females. We were able to complete interviews with 11 of the 16, for a response rate of 68.75%.

After completing these interviews, we determined that we were nearing a saturation point with responses, and did not aggressively pursue replacement respondents. The semi-structured interviews asked students to describe their experiences in their first semester, in terms of their classes, social lives, work patterns, concerns, and experiences on campus. Transcripts were reviewed by no fewer than four people to identify patterns in the interviews. These patterns were then compared to published studies, and when possible, we replicated survey questions from these studies. Specifically, we used an index of Identification with Engineering from Jones et al (2010), a self-assessment of math ability and an index of professional role confidence from Cech et al (2011), and multiple items from the University of Pittsburgh School of Engineering Student Assessment System (Besterfield-Sacre 2005), organized into indexes of professional interest, engineering skills, and confidence in academic skills. In addition, based on recurring patterns in the interviews, we devised new measures of climate in engineering, time management, high school preparation, impressions of several elements of the first-year curriculum and pre-professional co-curricular sequence, personal characteristics, and differential experiences by gender, race, sexual orientation and financial situation. Appendix 1 contains a list of all items and how they are organized into indexes.

Conducting the pilot study

To validate the instrument's measures, we conducted a pilot study. The pilot survey was distributed electronically through an email invitation to the population of first-year students in the School of Engineering (N = 172). The initial invitation was followed that same day with an email from the Dean of Engineering, encouraging students to participate. Email reminders were sent to non-respondents at the following intervals: t+2days (n = 155), t + 7 days (n = 149), t + 9 days (n = 134); in addition, a final emailed request from the Dean was sent at t+10 days. Both the final reminder and the final Dean's message included the date when the survey would close (3 days after reminder, 2 days after Dean's message). In total, 58 students started surveys (response rate = 33.72%) and 55 completed surveys were recorded with Qualtrics software (response rate = 31.98%), although we received no more than 52 valid responses on any of the demographic questions and no more than 48 valid responses on the subject questions. Analysis of distributions of the responses also led to the removal of one case, who indicated the same answer on all subject questions.

From this pretest, <u>we concluded the following about survey administration</u>: (1) a representative sample of first-year engineering students is not likely to complete an electronic survey without incentives to do so; (2) there were no apparent barriers to electronic administration or the length of the survey, because the completion rate *once started* was 94.83%; and (3) the largest number of students completed the survey after the final reminder was sent and reinforced a day later with a message from the Dean (n = 20, compared with 17 after initial invitation, 6 after first reminder, and 12 after second reminder), suggesting that the deadline was a strong incentive to complete.

Our sample is comprised mainly of white, non-Hispanic males (see Table 1). Nearly one in five have a father who is an engineer, and more than one in four participated in a high school engineering or robotics club. They rate their own math skills "compared to an average person your age" as at least "above average." We have not determined how these characteristics match up with the population of first-year engineering students. However, the primary purpose of the pilot was to validate the instrument rather than collect representative data.

Table 1: Sample Attributes*

	Mean	**s.d.**	**N**
Sex (1 = Male, excluding "other" gender)	.87	.344	45
White, Non-Hispanic	.65	.480	52
Black/African American	.02	.139	52
Hispanic/Latino/a	.08	.269	52
Asian/API	.12	.323	52
Father Engineer	.18	.389	39
Math Ability (1 to 5 scale, 5 = "Top 10%")	4.16	.673	45
HS Eng/Robotics Club	.28	.455	46

* All variables on binary scale (1 = yes), except as noted above.

Findings: Reliability of Measures

From this pretest, we have concluded that measures from previously published studies produced similarly valid measures based on a Cronbach's alpha score of 0.70 or above (see Table 2). In other words, our students appear to be comparable to other engineering students in terms of reporting their own identification with the engineering profession, professional confidence, professional attitudes, and self-assessment of engineering skills.

Table 2: Reliability of Previously Validated Indexes

Indexes	**Items**	**Valid N**	**Cronbach's Alpha**
Jones Identification with Engineering	4	48	.823
Cech Professional Confidence	7	44	.878
PSEAS Engineering Profession	12	47	.825
PSEAS Engineering Skills	14	41	.753

As expected, the PSEAS items on academic skills did not cohere into an index (alpha = .279), but factor analysis (principal components analysis, VARIMAX rotation) of these items identified three inter-related skill sets loading onto three factors: math/physics/computer science; writing/speaking; and chemistry (See Table 3). Self-assessed engineering skills did not load cleanly on any factor. Factor 1, which comprises physics, calculus, and computer skills also had a high bivariate correlation with self-reported math ability ($r = .616$, $p <.001$), while neither of the other factors had a significant bivariate relationship with self-reported math ability. We find this pattern of self-assessed skill sets to be an important issue to examine in future research.

Table 3: Component Matrix

	Component		
	1	2	3
Chemistry Skills	.155	-.508	.568
Physics Skills	.716	-.131	.023
Calculus Skills	.673	.079	-.397
Engineering Skills	.525	.298	.595
Writing Skills	-.357	.682	-.096
Speaking Skills	-.017	.691	.416
Computer Skills PSEAS	.707	.308	-.251

In addition, several of our new indexes appeared to be reliable: general climate in engineering, reactions to a required, no-credit "Introduction to Engineering" course, reactions to a required course on "Fundamentals of Engineering", reactions to science correlate courses, and reactions to general education courses (see Table 4). Low numbers of respondents for the Fundamentals index result from the fact that only about half of first-year engineering students register for this course in their first semester; students who have not yet selected a major within engineering ("open-options" engineering) may not register for this course in the fall semester. Instead of Fundamentals of Engineering, about half of first-year engineering students complete an additional science correlate course in computer science during their first semester. It is not clear why so few students answered the questions in this matrix—students were least likely to provide a response to the item "My professors clearly convey the material in the [science correlate] courses" (n =27) and this item also had the lowest mean score. But no more than 39 students answered any of the items about science correlate classes, compared with 43-45 respondents for the seven items in the matrix that preceded it and 45 respondents for all five items in the matrix that followed it. Interviews with first-year students suggest that many of them were struggling with these classes, and this might explain some of their hesitancy to respond. This is also worth following up in future research.

Table 4: Reliability of New Indexes

Indexes	**Items**	**Valid N**	**Cronbach's Alpha**
Climate in Engineering	8	47	.752
Reactions to Intro. to Engineering Course	10	46	.768
Reactions to Fundaments of Eng. Course	10	18	.808
Reactions to Science Correlate Courses	6	21	.770
Reactions to General Education Courses	8	45	.861

Students did not respond consistently to five questions asked about required pre-professional activities, such as attending "technical seminars," joining student chapters of professional organizations, and participating in networking and mentoring events. Participation in technical seminars and joining professional organizations had a significant bivariate correlation ($r = .528$, $p < .001$), as did student impressions of both junior/senior and alumni mentors ($r = .511$, $p = .001$). Informal mentoring by students further along in the engineering program was not significantly correlated with any of the other items.

We also recorded students' impressions on how gender, race/ethnicity, sexual orientation, and financial condition affected their experiences as engineering students. While we could not find systematic patterns based on attributes alone (e.g., gender, race/ethnicity), we found patterns in the way students answered that are consistent with emerging understanding of micro-inequalities (see Table 5). For example, students consistently responded in how other students and faculty in engineering treat them as well as whether they believe "I have enough money to purchase what I need to complete requirements in my classes." These items cohere into an index that we call Equality of Treatment. Experiencing discrimination on the basis of or being made aware of one's gender, race/ethnicity, sexual orientation, or financial status organized into an index of Unequal Treatment. How one's gender, race/ethnicity, sexual orientation, or financial status affected one's decision to major in engineering or is believed to affect one's experience as an engineering student are organized into an index of Sensitivity to Inequality. These indexes are highly intercorrelated, with Equality of Treatment being negatively correlated with both Unequal Treatment ($r = -.507$, $p < .001$) and Sensitivity to Inequality ($r = .581$, $p < .001$). The Unequal Treatment and Sensitivity to Inequality indexes were positively correlated ($r = .646$, $p < .001$). Further analysis finds that the indexes measuring Unequal Treatment and Sensitivity to Inequality may be combined into a single index, although there may be theoretical reasons for keeping them separate.

Table 5: Inequality Indexes

Indexes	**Items**	**Valid N**	**Cronbach's Alpha**
Equality of Treatment	7	45	.913
Unequal Treatment	7	45	.811
Sensitivity to Inequality	7	45	.767
Treatment + Sensitivity	14	45	.866

Several items that we expected to cohere into indexes did not (see Table 6). We are continuing our investigation into why time management, high school preparation, and personal characteristics did not produce consistent results.

Table 6: Conceptual Indexes without empirical validation

Indexes	**Items**	**Valid N**	**Cronbach's Alpha**
Time Management	4	46	-.208
Preparation	3	46	-.545
Personal Characteristics	11	45	.509

Findings: Distributions of Measures

We created indexes based on the reliability measures indicated above. In all indexes, mean scores are calculated. To maximize responses, cases that are missing responses on any items in the index are assigned the mean for the items for which they did respond.

Virtually all of the indexes produced a normal or near-normal distribution of responses (see Table 7). Where outliers did occur in the distribution, we could find no discernable pattern to which cases were outliers across the indexes.

Table 7: Descriptive Statistics

	Mean	s.d.	N	Outliers
PSEAS Engineering Profession	4.1722	.49298	48	1, 2, 13, 47
Jones Identification with Engineering	6.2135	.64203	48	4, 25, 27
Climate in Engineering	4.1303	.54296	47	4
PSEAS Engineering Skills	3.8076	.44423	46	1
Reactions to Intro. to Engineering Course	3.6630	.57556	46	4
Reactions to Fundaments of Eng. Course	3.7889	.66145	18	13
Pre-Professional Sequence	3.9442	.54927	46	Normal
Cech Professional Confidence	3.3095	.48969	45	4
Reactions to Science Correlate Courses	4.2924	.48741	44	Normal
Reactions to General Education Courses	3.1028	.90817	45	Normal
Unequal Treatment	1.6476	.64221	45	3, 4, 19,35,40
Equality of Treatment	4.4444	.67229	45	2, 13
Sensitivity to Inequality	1.4603	.57458	45	1, 2, 3, 19, 53
Treatment + Sensitivity	1.55	.55203	45	3

Conclusion

Drawing on formative interviews, we created a robust survey instrument that can be deployed to understand the professional development of first-year engineering students. This methodology allowed us to first validate measures used by other scholars within a student population in a primarily undergraduate institution, rather than the more common R1 context. In addition to validating established measures, we developed new measures to understand the role of this different context, in particular, the liberal arts curriculum and specific curricular and co-curricular activities within engineering. These measures offer additional value for programs seeking to build PFE activities into their curricula, as they directly assess student reactions to common components of a holistic program in engineering. Beyond these contributions, our instrument also includes novel measures to further our understanding of how program climate affects student professional formation as engineers. Our analysis suggests that a student's perception of whether there is equal treatment and sensitivity to inequality better predicts professional formation than their individual demographic factors such as race, gender, sexual orientation, and/or class. Thus, these measures will allow programs and scholars to examine the need for and impact of diversity and inclusion efforts beyond simply the retention of underrepresented students. As our next steps, we will tailor this instrument to juniors/seniors and new/long-time alumni via a similar process of formative interviewing and pilot testing. By the end of this project, we will have a robust set of instruments for program assessment and primary research with professional and pre-professional engineers suitable for longitudinal comparison.

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Appendix: Items in Each Index

Identification with Engineering (Jones et al 2010)

- Being good at engineering is an important part of who I am.
- Doing well on engineering tasks is very important to me.
- Success in engineering school is very valuable to me.
- It matters to me how I do in engineering school.

Professional Role Confidence (Cech et al 2011)

- Developing useful skills
- Advancing to the next level in engineering
- My ability to be successful in my career
- Engineering is the right profession for me
- Selecting the right field of engineering for me
- Finding a satisfying job
- My commitment to engineering compared to my engineering classmates
- Rate your math ability compared to an average person your age:

PSEAS Engineering Profession (Besterfield-Sacre et al 2005)

- I expect that engineering will be a rewarding career.
- The future benefits of studying engineering are worth the effort.
- Engineers are well paid.
- Engineers contribute more to making the world a better place than people in most other occupations.
- I enjoy the subjects of science and mathematics the most.
- I will have no problem finding a job when I have obtained an engineering degree.
- Engineering is an occupation that is respected by other people.
- I enjoy taking liberal arts courses more than math and science courses.
- My parent(s) want me to be an engineer.
- Engineering involves finding precise answers to problems.
- I am studying engineering because I enjoy figuring out how things work.
- I chose engineering because I like to build things.

PSEAS Engineering Skills (Besterfield-Sacre et al 2005)

- I feel I know what an engineer does.
- Studying in a group is better than studying by myself.
- Creative thinking is one of my strengths.
- I need to spend more time studying than I currently do.
- I have strong problem solving skills.
- Most of my friends that I "hang out" with are studying engineering.
- I feel confident in my ability to succeed in engineering.
- I prefer studying/working alone.
- I am good at designing things.
- In the past, I have not enjoyed working in assigned groups.
- I am confident about my current study habits or routine.
- I consider myself technically inclined.
- I enjoy solving open-ended problems.
- I enjoy problems that can be solved in different ways.

Climate in Engineering
- I feel a sense of community within the School of Engineering.
- The engineering professors care about their students beyond their grades.
- Juniors and seniors in my major are welcoming and encouraging to first-year students.
- I feel comfortable interacting with professors in Engineering.
- All students are offered the same opportunities in Engineering.
- I feel comfortable interacting with other students in Engineering.
- Everyone in my major is friendly towards one another.
- My personality fits in with the personalities of the other students in my major.

Reactions to Introduction to Engineering Course
- It is an academically challenging course
- My professor seems to enjoy the material in the course
- My professor is available outside of class to help students with the material in the course
- My professor clearly conveys the material in the course
- Tutoring is or would be useful to me for this course
- I find this course to be enjoyable
- Peers in this course often discuss the course outside of class hours
- My high school classes prepared me well for this course
- I feel like this course has prepared me for sophomore-level engineering courses.
- I enjoyed the guest speakers in [Course]

Reactions to Fundamentals of Engineering Design Course
- It is an academically challenging course
- My professor is knowledgeable about the material in the course
- My professor seems to enjoy the material in the course
- My professor is available outside of class to help students with the material in the course
- My professor clearly conveys the material in the course
- Tutoring is or would be useful to me for this course
- I find this course to be enjoyable
- Peers in this course often discuss the course outside of class hours
- My high school classes prepared me well for this course
- I feel like this course has prepared me for sophomore-level engineering courses.

Reactions to Science Correlate Courses
- These are academically challenging courses.
- My professors clearly convey the material in the courses.
- Tutoring is or would be useful to me for these courses.
- These courses are relevant to my engineering major.
- I find these courses to be enjoyable.
- I feel like these courses have prepared me for my engineering major.

Reactions to General Education Courses
- I enjoy taking courses outside of engineering.
- [General education] classes are a good use of my time.
- I wish I could take more [General education] classes.
- Fitting [General education] classes into my schedule is challenging.
- It is important for engineers to learn to write well.
- The [First seminar] requirement is worthwhile for TCNJ engineering students.
- My [First seminar] was beneficial to my understanding of the world around me.
- I enjoyed my [First seminar] overall.

Equality of Treatment

- Students of all [genders]/ [races/ethnicities]/ [sexual orientations] are treated equally by professors and staff. (3 items)
- Students of all [genders]/ [races/ethnicities]/ [sexual orientations] are treated equally by other students. (3 items)
- I have enough money to purchase what I need to complete requirements in my classes.

Unequal Treatment

- I have been discriminated against because of my [gender]/ [race/ethnicity]/ [sexual orientation]. (3 items)
- I am often made aware of my [gender]/ [race/ethnicity]/ [sexual orientation]. (3 items)
- Most of my peers seem to have more money than I do.

Sensitivity to Inequality

- My [gender]/[race/ethnicity]/[sexual orientation]affects my experience as an engineering major. (3 items)
- My [gender]/[race/ethnicity]/[sexual orientation]influenced my decision to major in engineering. (3 items)
- My family's income affects my experience as an engineering major.

Time Management

- I find myself completing tasks at the last minute.
- I complete assignments that are more interesting first and then everything else.
- I am satisfied with the way I manage my time.
- I often feel overwhelmed by my coursework.

Preparation

- My high school curriculum prepared me well for TCNJ's engineering classes.
- I feel like I am less prepared than my classmates for the TCNJ engineering curriculum.
- I have more work than my non-engineering peers.

Personal Characteristics

- I consider myself to be shy.
- I am very diligent, especially regarding my schoolwork.
- I do not hesitate in reaching out to my professors for help or advice.
- I am comfortable with taking initiative and often do so.
- I enjoy taking on leadership roles.
- I am always eager to learn.
- I enjoy working with classmates.
- I make sure to spend time away from my studies.
- I am interested in the creative aspects of engineering.
- I am interested in the technical aspects of engineering.
- I consider myself to be a competitive person in terms of academics.