
AC 2011-2087: FIRST YEAR ENGINEERING STUDENTS ARE STRIKINGLY IMPOVERISHED IN THEIR SELF-CONCEPT AS PROFESSIONAL ENGINEERS

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Fred is Co-Principal Investigator and Director of The Full Potential Initiative, an NSF-funded longitudinal study of the development and influence of implicit attitudes about intellectual ability and academic belonging. His findings have demonstrated that biased implicit associations in the minds of students, teachers and professionals are not simple functions of the stereotypes in their environment, but vary predictably with their personal experiences and identities. Female and male scientists, for example, differ greatly in the strength of their implicit stereotype of science as male (weak stereotyping among the women but strong among the men), even though they are both equally aware of the cultural stereotype. A key ongoing focus of his research is on the causal role that such varying implicit associations may play in shaping identities and contributing to perseverance in scientific studies and careers. Fred's publication topics have included comparisons of web- and laboratory-based implicit cognition experiments, the relationship between implicit and explicit attitude measures, ethnic and gender differences in science graduation at selective colleges, and standardized testing in college admission.

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First year engineering students are strikingly impoverished in their self-concept as professional engineers

Recruitment to and retention of students in engineering programs and engineering careers is problematic. While the number varies considerably by institution, nationally a third of students drop out of science and engineering undergraduate programs by their second year; only a third complete their science or engineering degree by six years. Students intending a science or engineering major in their freshman year often switch to other academic departments, and approximately 20 percent drop out of college altogether ¹.

Recruitment and retention of women in engineering is a particular concern. Despite decades of gender-gap-closing in science and math achievement, computer science and engineering remain disproportionately male at the collegiate level and beyond. Scientific fields, including biological sciences and chemistry, have seen notable increases in the fraction of degrees awarded to women in the past decade, but engineering has not ². Women both select engineering majors at a lower rate than men, and drop out of science and engineering programs at a higher rate than do men ².

Overt discrimination against women's participation in engineering is widely considered a thing of the past ³. Unfortunately, workplace culture has been explicitly declared by female survey respondents to play a critical role in determining their persistence in engineering careers ⁴. Largely unexplored, however, is the role of the *subconscious* in determining persistence in engineering majors and careers – this is the domain of implicit cognition.

Explicit and implicit cognition are related but distinct concepts ⁵. Explicit cognition includes conscious choices, judgments, and declarations (e.g. “I believe that men and women are equally good at math.”). In contrast, implicit cognition operates without conscious awareness or control, and mediates thought, feeling, and action (e.g., ⁶⁻⁹). Implicit attitudes (e.g. “Math is good.”) and stereotypes (e.g. “Engineers are male.”), along with self-concept (e.g. “I am male.”) interact with one another in the prediction of science, technology, engineering, and mathematics (STEM) interest and achievement ^{10,11}. College students are both explicitly and implicitly biased in their stereotype of engineers as being male ¹².

Implicit attitudes, self-concepts, and stereotypes about science, technology, engineering, and mathematics (STEM) have been implicated in the tendency toward STEM majors or careers ^{13,14}. This raises the question, how strong are the implicit self-associations of engineering students and engineering professionals with engineering as opposed to other majors or career paths? Can this tell us something about current trends in the recruitment and retention of engineers?

Importantly, a change in the strength of association in one of these implicit constructs (e.g., attitude) is theorized to trigger a change in one or both of the other constructs (e.g. stereotypes and/or self-concept) ¹³. For example, subliminal priming of test subjects with the female stereotype (i.e., women are not mathematically inclined) causes women's explicit and implicit math attitudes to shift ¹⁵. Similarly, women's — but not men's — implicit math attitude changed as a function of whether the experimenter was male or female ¹⁶. Also found to influence STEM performance is the ratio of male to female peers in the immediate environment ^{17,18} and interactions with an *implicitly* sexist male peer ¹⁹.

These studies suggest that we may be able to influence implicit attitudes toward engineering, and along with them performance and retention, through high-impact educational activities. For example, if a young woman's affinity for engineering is boosted as a result of feeling engaged,

connected and successful working on a design/build project, we would expect that any stereotype she might hold about women as engineers would be attenuated and her implicit self-concept as an engineer strengthened. Nosek and colleagues¹⁰ found precisely this pattern for the implicit math attitudes, gender stereotypes, and self-concepts of Yale undergraduates and for a more diverse sample of Internet volunteers^{10,11}.

To better understand the biases inherent to freshman engineering students and whether they can be changed in a classroom setting, we used robust web-based tools to repeatedly measure their explicit and implicit attitudes toward self, math, engineering, and careers. Our objectives were:

- (a) Measure the implicit biases of freshman engineering men and women regarding STEM.
- (b) Determine whether engineering students and professionals are implicitly self-associated with engineering.
- (c) Determine whether project-based learning increases freshman students' self-association with engineering.

Methods

We employed the Implicit Association Test (IAT)²⁰ and a recent variant, the Brief Implicit Association Test (BIAT)²¹, to measure association strengths between concepts (e.g., math and languages) and evaluations (e.g., good or bad) or attributes (e.g., male or female). In the IAT, participants categorize a series of stimuli pictured in the center of a computer screen into four categories (e.g., male, female, science, liberal arts; see Figure 1). Only two keys are used to accomplish the sorting – one on the left of the keyboard and one on the right. For example, in the “stereotype-congruent” example given in Figure 1A, the left key would be used to categorize either a Math stimulus (e.g., “Number”) or a Male stimulus (e.g., photo of a man), while the right key would be used for Language Arts or Female stimuli. The dependent variable is the response time to make each categorization accurately. The average response time in this condition is compared to a second in which Language Arts and Male categories share one response key and Math and Female share the other (Figure 1B). The implicit effect is defined by the difference in a person's average response time between the two conditions, scaled by the overall variation

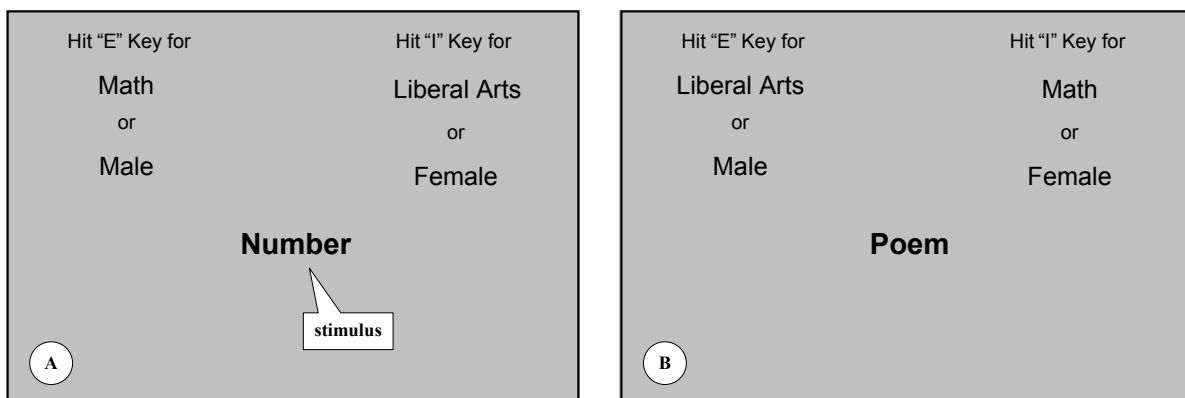


Figure 1: Example of one of the IATs delivered in this study. See the text for a detailed description.

(standard deviation) of their response times to yield an effect size score similar to a Cohen's d ²². The IAT has detected gender differences in STEM attitudes and predicted real-world STEM outcomes such as calculus performance^{10,14}, and countries' gender-gaps in teenagers' science and math achievement²³.

An example of the sort of IAT we employed can be experienced by entering the Demonstration portal at <https://implicit.harvard.edu/>. The "Gender-Science" IAT is reflected in Figure 1. This online 10-minute evaluation session is used to assess implicit science and liberal arts stereotypes and their relationship to explicitly reported STEM attitudes, identities and achievement. Results from over 500,000 volunteers shows that over 70% evidence an implicit bias associating men with science and women with liberal arts, while only 10% evidence the reverse^{22,24,25}.

Three IATs were used in the current study, (1) math vs. language arts self concept (self vs. other), (2) math vs. language arts stereotype (male vs. female), and (3) science vs. liberal arts stereotype (male vs. female). In addition, we assessed students' and professionals' implicit self identification with four career domains – engineering, medicine, publishing, and law – using the BIAT format; BIAT allows comparison of more than two concept pairs during the same session.

Study populations

Students' engineering and career-related explicit and implicit attitudes, stereotypes, and self-concepts were measured online three times during their first semester in engineering. This study was approved by the Social and Behavioral Sciences IRB at the University of Virginia. Students were given all-or-nothing 5% course credit for completing all three computer-based evaluations. The student participants were given written material on the general nature of the evaluations, along with contact information to have their questions answered. Participation rate exceeded 90%.

In the end we assessed 187 students in five Introduction to Engineering (ENGR 1620) sections. Each section of the course was taught by a different instructor; two instructors were from Biomedical Engineering and used a common curriculum. The other three sections were taught by instructors from Systems and Information Engineering, Materials Science Engineering, and Mechanical and Aerospace Engineering. Our student study population was 56% male, with 95% between the ages of 17 and 19. The racial distribution was 63% white, 14% east Asian, 8% south Asian, 5% black, 1% Pacific Islander, and the balance (9%) of mixed race. Ethnically 90% were non-Hispanic and 4% Hispanic/Latino. Six percent were of undeclared ethnicity.

We conducted a comparable BIAT study of practicing engineering and other professionals as a "featured task" in fall of 2009 at the Project Implicit web site (<https://implicit.harvard.edu/>). Respondents included 290 engineers, 254 medical professionals (doctors, dentists, etc.), 340 legal professionals (lawyers, judges, and related), and 158 medial and communications professionals. Eighty percent of the engineer respondents were male, consistent with the professional population.

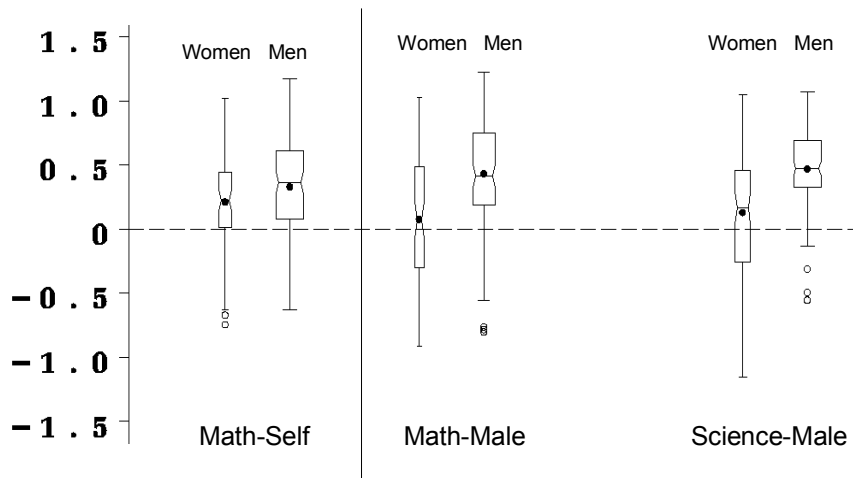


Figure 2: Implicit associations (ordinate) of identity between math and self, and math/science and male (abscissa). Box length indicates the center two quartiles. Notches on the box indicate ± 1 standard error. The width of boxes is related to group N.

Male engineering students more strongly associate math and science with gender stereotypes

As expected for engineering students, these women's implicit math self-concepts were robust. That is, they more easily associated terms denoting "self" with mathematical terms than with language arts terms. It was even easier for the men, however, whose math-self associations were stronger than the women's by $d = .31$ (first panel of Figure 2). In terms of stereotypical gender-engineering associations, women and men did not differ in the strength of their explicitly self-reported bias; each, on average, indicated a moderate association of engineering with men. Implicitly, however, men and women differed greatly in the strength of their associations of math and science with gender. Men strongly associated both math and science with male, while women evidenced *no* differential gender association for math and only a weak association of science with male. These data are compatible with the findings of Smyth et al.²⁶

Neither first year engineering students nor engineering professionals self-identify with engineering careers

Colloquially, this cohort of engineering students did not strongly conceive of themselves as engineers as opposed to doctors, lawyers, or writers. In this group of first semester engineering students, for whom career paths within STEM sub-disciplines are far from certain, engineering was not more strongly associated with the self than was medicine (Figure 3A). The STEM fields of engineering and medicine were each significantly more strongly associated with the self than were the non-STEM fields of law and publishing. However, the most striking result is the *weakness* of the self-association; no effect size exceeded 0.25.

We compared these data to those from professionals in each of these domains. The same BIAT was given online to practicing engineers, physicians, lawyers and media professionals. The results (Figure 3B) are startling! While practitioners of medicine, law, and publishing strongly associate themselves with their own profession relative to some others, this is not the case for

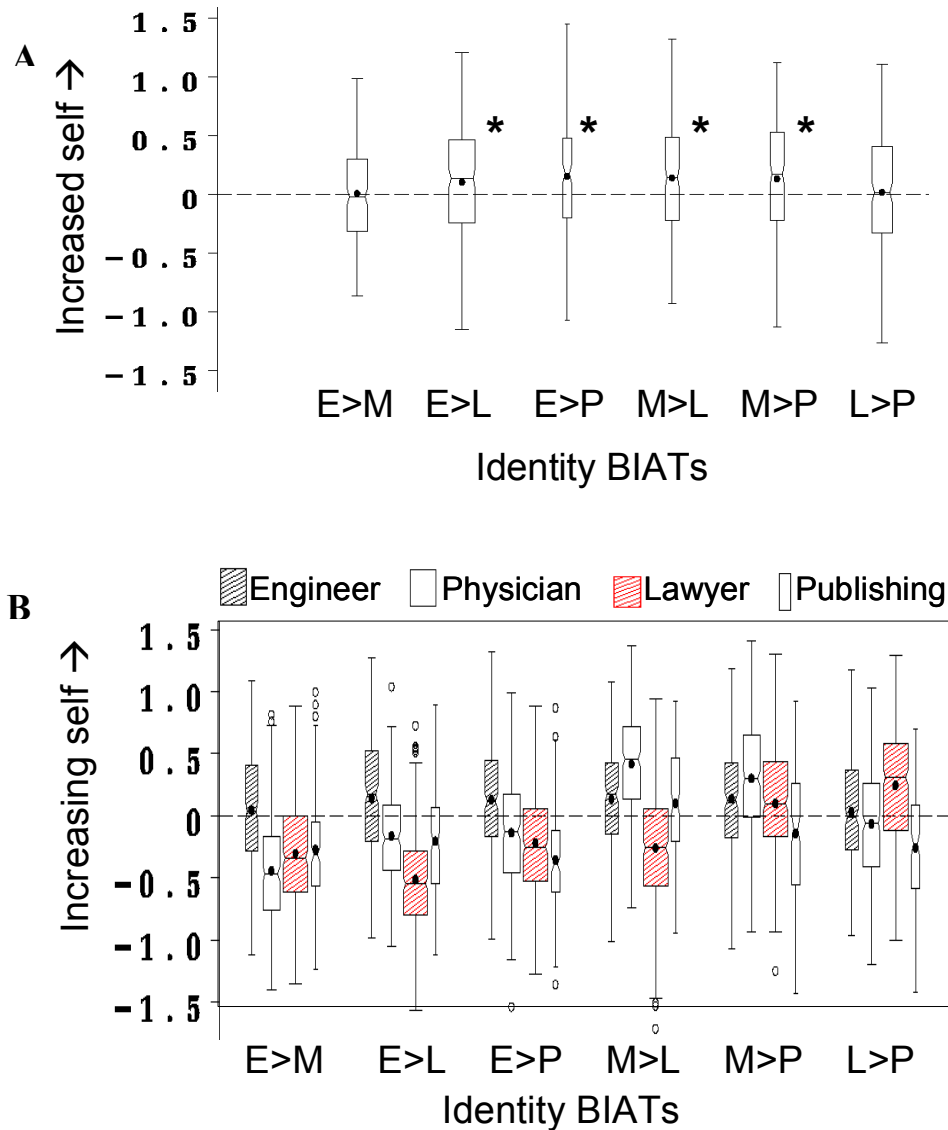


Figure 3: Weak self-associations of engineers with the engineering profession. The ordinate ranks the ability of the respondent to self-associate with one profession relative to another. The abscissa indicates the comparison being made— engineering (E), medicine (M), law (L) or publishing (P). A: Implicit self-associations of first year engineering students with professions. B: Implicit self-associations of practicing professionals with professions. Note the lack of self concept (near zero score) for engineers comparing engineering to any other professional domain. *Significantly non-zero ($p < 0.05$).

engineers. Professional engineers' implicit association with careers almost perfectly overlays the first year engineering students; they only weakly associate with engineering compared to other careers, while others strongly associate with their own professions.

Interestingly, men and women differed significantly only in the two implicit self-concept contrasts that most directly reflect stereotypes: engineering vs. publishing and medicine vs. publishing. Publishing was defined in the BIAT with the words *writing, essay, editing,* and *newspaper*, which are mostly stereotypically associated with women.

Also interesting was that there were no course section- or time-dependent changes in implicit career bias despite the fact that the sections differed radically in terms of intended major, course content, and the degree of hands-on building involved (Figure 4). Sections ranged from large design/build projects (BME, ME, SE) to smaller projects or conceptual design (MS).

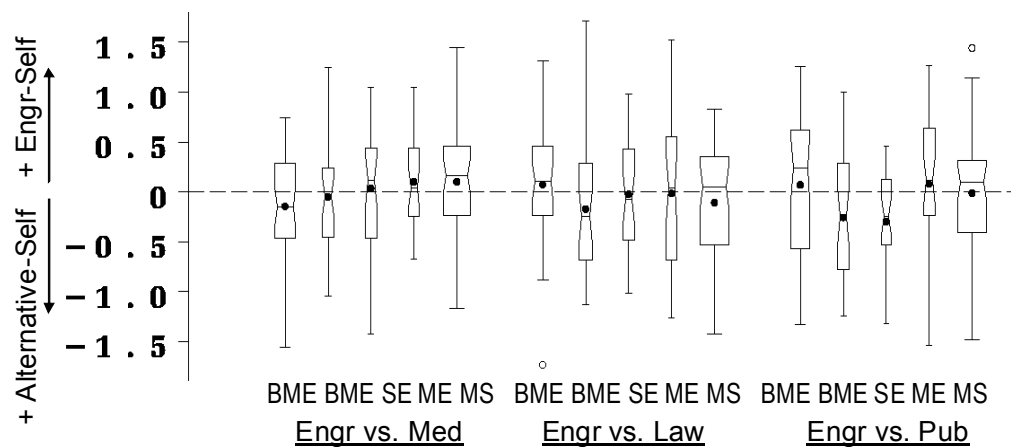


Figure 4: Implicit Engineering Identity Change Scores (final score minus mid-semester score) by class section. Those above the dashed line have increased implicit association with engineering relative to the alternate career indicated in the bottom row. BME, Biomedical Engineering; SE, Systems and Information Engineering; ME, Mechanical Engineering; MS, Materials Science Engineering.

Other gender differences

We asked questions that gauged the students' conscious values, choices and judgments concerning engineering. Examples of questions we asked include "I find engineering exciting." "I enjoy building things." Vocational interests, including Holland's RIASEC constructs²⁷, were measured with the Personal Globe Inventory-Short questionnaire (PGIS)²⁸. By Holland's convention, career associations are commonly referred to by the acronym RIASEC – realistic, investigative, artistic, social, enterprising, and conventional.

In the first week, men reported significantly greater liking than women did of building things ($d = .43$), confidence in their computer-based problem-solving ability ($d = .40$), and scored higher on the realistic "doing of things" dimension of vocational interest ($d = .70$). Women were higher than men in self-assessments of creativity ($d = .35$) and on the "social" dimension of vocational

interest ($d = .86$, Figure 5). Male and female students did not differ in their response to the statement “I find engineering exciting.”

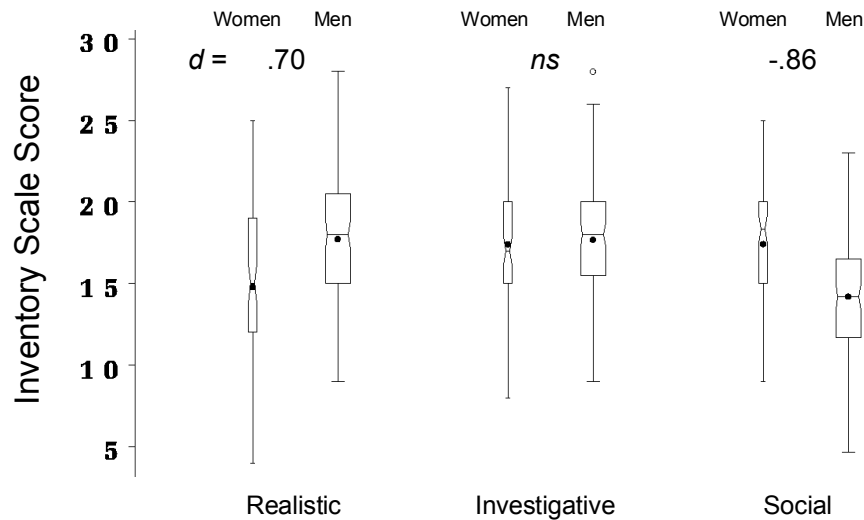


Figure 5: Vocational interest scores of men and women differ, particularly in the Social dimension of Holland’s RIASEC classification.

When asked about possible causes of the dearth of women among top university science faculty, women rated more strongly than men the importance of discrimination, whether conscious or unconscious, in hiring and promotion. At semester’s end, women were also more likely than men (30% vs. 8%; $d = .48$) to report that gender stereotypes hurt their own performance in the Introduction to Engineering course. Of note, women’s ratings of these latter two items were uncorrelated ($r = .01$); that is, the early semester beliefs about the general effects of discrimination were not related to end-of-semester beliefs about gender stereotypes affecting personal performance.

Finally, we measured participants’ performance on the Vandenberg-Kuse mental rotation test²⁹ which scores one’s ability to match two-dimensional rotations of simple three-dimensional objects. Mental rotation ability is both a predictor of certain kinds of math and science success and one of the cognitive domains in which the largest gender differences are observed. Men’s mental rotation scores were higher by $d=0.56$ ($p<0.05$). Though this specific gender difference was unknown to the participants, this gap was paralleled by men’s higher self assessment of ability in this area ($d=0.51$, $p<0.05$).

Conclusions and future directions

Our results suggest a surprising lack of self-concept as engineers, both among freshman engineering students and among practicing engineering professionals. In contrast, other professionals associate strongly with their own career. To our knowledge, this is the first report of implicit self-associations with career domains, and the results raise serious questions about how biases and stereotypes affect engineering training.

We hypothesize that this lack of implicit association of self with engineering is a significant factor in the lack of student persistence in engineering majors and careers. Persistence in

engineering is an issue, particularly in fields such as Biomedical Engineering, where a significant fraction of students go on to medical school³⁰. This may be particularly true for women, who are unbiased in their female versus male association with math and science (Figure 2), who may be influenced by the strong implicit bias of their male peers (similar to¹⁹), and who are stronger than men in their self association with social careers. “Social” personality types tend toward supporting, helping, and nurturing work environments, while “Realistic” personality types (with which men more closely associate) are given to practical, hands-on, and tool-oriented work environments. Further, our data suggest that women’s perceptions of bias in the work place⁴ are paralleled in undergraduate teams, even as early as the first semester, where nearly a third felt that their gender had a negative impact on their performance in the course.

A novel and particularly worrisome observation is that practicing engineers too lack strong engineering self-concepts (Figure 3B). The reason for this is not at all clear. While one might theorize that the higher levels of education typical of engineers results in decreased biases overall, what little data exists on the effect of education is mixed. On the one hand, graduate-level students in STEM fields more strongly associate math with their own gender than do undergraduates³¹, indicative of stronger bias. In contrast, more highly educated persons are less biased against persons with mental disabilities than are less educated persons³². Likewise, our observation that physicians, also highly educated in STEM, strongly associate with their own profession also argues against the theory that educational level or background gives rise to the “unbiased engineer” – an engineer whose self-association with their own profession is remarkably impoverished relative to other professionals.

We believe that it is vital to anticipate and address the possible downstream effects of this impoverishment in professional self-association. Just as exposure to an implicitly *biased* peer can influence science and math performance¹⁹, might the inverse be true? Might exposure to implicitly *unbiased* engineering faculty or professionals (in terms of the profession) lessen the engineering self-concept of their students? If this were true we could hypothesize that student persistence in engineering would be enhanced when they interact with faculty with strong explicit or implicit pro-engineering biases relative to those who exhibit a more egalitarian attitude to career paths. This might be addressed through a longitudinal study of implicit self-concept of a student cohort together with their instructional faculty.

Of course there are students in the statistical distribution with very strong engineering self-concepts. Who are these students? What is it in their present or past that distinguishes them from students with weaker engineering self-concepts? Do students with strong engineering self-concepts persist in engineering majors and careers more than students with weak self-concepts? All these questions remain to be answered. However, we postulate that early interventions to instill pro-engineering biases and self-concepts may enhance downstream persistence in engineering careers. This one-semester pilot data lays a foundation for a multi-year longitudinal study with that aim.

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