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Clinician-engineer career bias and its relationship to engineering design self-efficacy among Biomedical Engineering undergraduates

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Background

Biomedical engineering undergraduates are often drawn to clinical practice rather than to careers in engineering – 54% according to one study in 2008 [1]. An informal survey of recent career outcome dashboards suggests that this remains the case, though medical schools are not called out separately in those reports. These data imply an equivalent *self-concept* among BME majors as clinicians than as engineers. *Self-concept* as a psychological construct is "the individual's belief about himself or herself, including the person's attributes and who and what the self is." [2] *Self-concept* is often discussed alongside *self-efficacy*, the latter being a belief in one's ability to attain successful outcomes. *Self-efficacy* is frequently studied because it is easily measured through self-reports (as is *self-concept*), and because it is positively correlated with successful academic outcomes [3]. Both constructs are general, and an infinite array of subtypes can be defined. *Self-concept* and *self-efficacy* are fundamentally different constructs, yet there is interplay. The former may be a better mediator of affect – how one feels about a task – while the latter is a better mediator of academic achievement [4]. Further, *self-concept* may positively influence *self-efficacy*.

We hypothesized that BME students' self-concepts and feelings of self-efficacy might relate to their unusual career goals (relatively speaking, among engineering fields). We therefore sought to explore BME students' *career self-concept* as engineers and as clinicians, and the relationship of those self-concepts to *engineering design self-efficacy* [5]. Both constructs are measured via instruments that rely on self-declarations – also known as explicit measures. Self-declarations, or *explicit* measures, of self-concept carry with them the concern of unreliability and bias – that they represent wishes about one's self rather than a measurement of underlying beliefs. Therefore, in addition to explicit measures we also used an *implicit* measure *self-concept* (engineer *versus* clinician) – an implicit attitudes test (IAT) [6]. We interpreted the resulting measure of implicit bias as a measure of *career self-concept*.

Methods

This research was approved by the University of Virginia Social and Behavioral Sciences IRB, protocol number 3236.

This study was conducted in concert with a second-year course in design for biomedical engineering students. The course itself was focused on the development of software, hardware, and fabrication skills of particular use to biomedical engineers [7]. These included CAD, microcontrollers, basic circuits, 3D printing, subtractive approaches to prototyping, and digital image analysis. The course culminated in a closed-ended team-based design project with a physical prototype due at the end.

Both explicit and implicit measures were delivered through Qualtrics online survey software. This survey was delivered before the second class session of the semester, and again in the week of final exams. The survey included:

1. The *ability* dimension of the *engineering design self-efficacy* instrument, described in [5]. This measures whether students believe they will be:
    a. *Able*, and
    b. *Motivated* to engage in engineering design tasks, whether they feel they will be
    c. *Successful* in doing so, and how
    d. *Apprehensive* they would be in performing such tasks.

    Likert responses on these four dimensions were scored on a 0-10 scale, with 0 being low confidence.
2. An explicit declaration of career interest, written as two questions and answered on a scale of 0-10:
    a. How interested are you today in becoming an engineer?
    b. How interested are you today in becoming a clinician?
3. A *career self-identity* IAT, which we designed for Qualtrics using the iatgen tool [8].

The Implicit Association Test (IAT) is a psychological test that relies on repeated measures of response latency to measure a subject's association with two concepts – in this case, between the

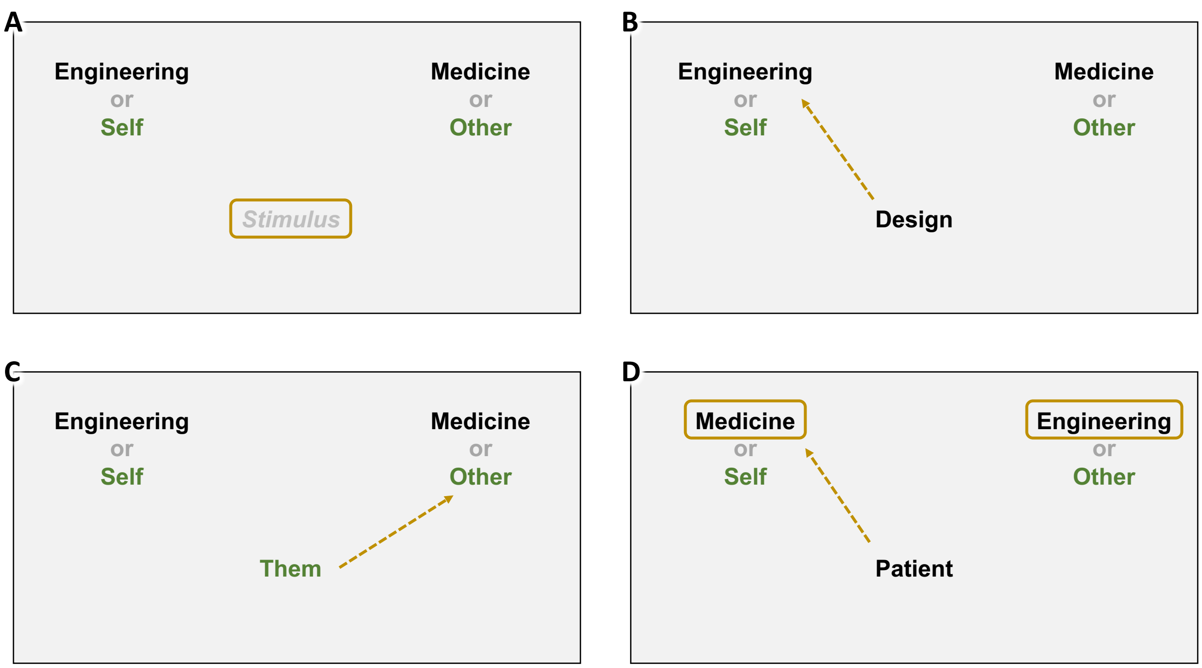

Figure 1: Illustration of the Implicit Attitudes Test (IAT). A: The stimulus is displayed in the center of the screen, and the user presses a key on the left or right-hand side of the keyboard to sort that stimulus into the appropriate category. B: In this example, the user would press the left-hand key to sort "Design" into the "Engineering category." C: In this example, the user would press the right-hand key to sort "Them" into a combination of either "Medicine or Other." D: At other stages of the test, the categories are switched and recombined on the screen. In this example, the stimulus "Patient" would be sorted into the categories of either "Medicine or Self." This is sometimes referred to as the "stereotype-incongruent pairing."

concepts of self and other, and the concepts of clinician and engineer. In the IAT, participants categorize a series of stimuli pictured in the center of a computer screen (Figure 1A) into those categories. 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" examples given in Figure 1B and C, the left key would be used to categorize "Design" as Engineering, and the right key would be used to categorize "Them" as Other. 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 Medicine and Self share one response key, and Engineering and Other share the other. The implicit effect is defined by the difference in a person's average response time between the two conditions, scaled by the standard deviation of their response times, to yield an effect size similar to Cohen's d [9]. The IAT has been used to show gender differences in STEM attitudes, and has predicted outcomes such as calculus performance [10], [11].

Ethnicity	Female	Male	Total
Asian	8	4	12
Black or African American		1	1
Hispanic	1	1	2
Multi-Race	2	2	4
Unknown	4	5	9
White	25	12	37
Total	**40**	**25**	**65**

Table 1: Cohort demographics

Analysis of data was performed in Microsoft Excel and in IBM SPSS Statistics. We excluded from analysis students who responded only to one of the two surveys (pre- or post-course). The demographics of students who were included in our results are shown in Table 1.

Results

Implicit and explicit measures

The IAT provides a bias score – in this case the magnitude of a student's bias toward self-identification with engineering (positive score), or self-identification with medicine (negative score). This bias score (*career self-concept*) typically falls within the range of -1.2 to +1.2. In contrast, our explicit measure of career interest was an absolute score, not a bias score, and was collected on a scale of 0-10. In order to compare these scores on comparable scales, we generated an *explicit career bias* score by subtracting their interest in

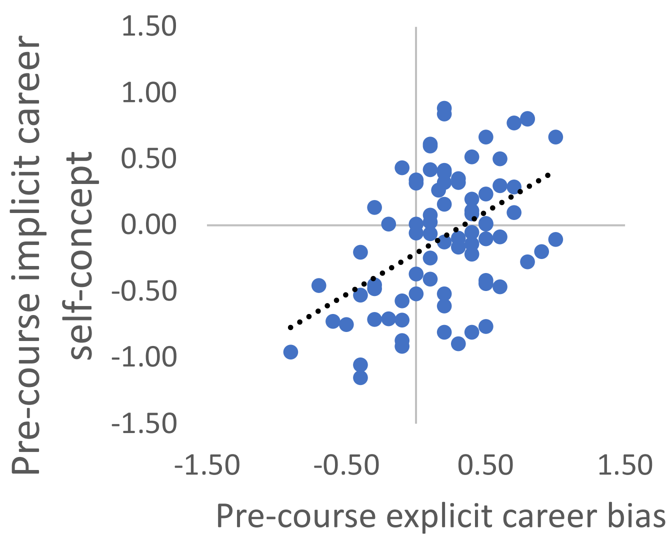

Figure 2: Pre-course implicit bias is predicted by explicit bias. Positive values indicate a bias toward engineering over medicine.

medicine from their interest in engineering and dividing by 10. Positive values in either score represent a bias toward engineering, while negative scores reflect a bias toward medicine.

As a measure of validation of our implicit measure, we found a significant correlation between BME students' beginning-of-course (pre) *explicit career bias*, and students' implicit *career self-concept* ($r = 0.48$, $p<0.001$, $N=76$). This is shown in Figure 2. *Explicit career bias*, and students' implicit *career self-concept* measured at the end of the course were also significantly correlated with one another (post; $r=0.56$, $p<0.001$).

On average the students in this study were unbiased in their implicit *career self-concept*. Mean scores measured at the beginning and end of the semester were only 0.27 ± 0.06 and 0.23 ± 0.07, respectively. Neither was significantly different from zero (unbiased) by unpaired t-test. This, however, varied greatly by student, with students having implicit bias scores ranging from -1.2 to +1.2 at the end of the semester. In contrast, *explicit career bias* was significantly different from zero at both the beginning and end of the semester – 0.15 ± 0.05 in both cases, $p<0.001$ – a small average bias toward engineering.

Changes over the course of the semester

When asked in the post survey if they felt their interest in either engineering or medicine as a career had changed over the semester, 34% reported that they felt it had. Interestingly, this perception is borne out by students' *explicit career bias*, but not by their implicit *career self-concept*. There was a significant difference in the post-pre changes in *explicit career bias* of students who felt their interests had changed compared to those who felt they had not ($p=0.029$), while the corresponding p value for post-pre implicit *career self-concept* was not significant at 0.367. By a ratio of 1.29:1 this change was in favor of engineering. The same ratio for *explicit career bias* was 1.17:1 in favor of engineering.

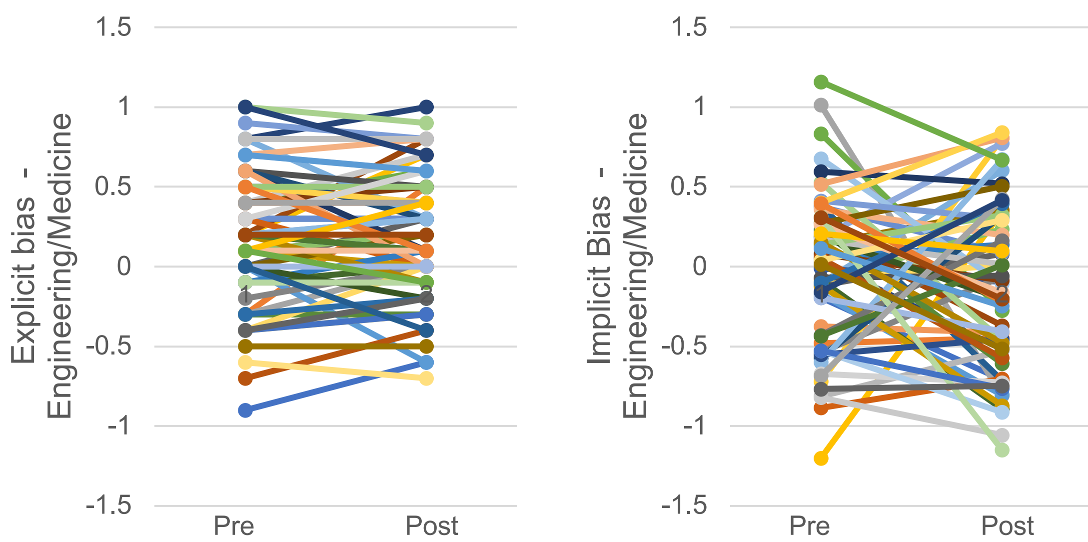

Figure 3: Pre- to post-course scores for explicit career bias (left) and implicit career self-identity (right). Each line represents an individual student. This representation was chosen to best emphasize the relative variability in the two measures, and also their relative changes over time.

Implicit *career self-concepts* were more variable than were *explicit career biases*, and they also changed more over time. This is illustrated in Figure 3, where two things are visually apparent; first, the points in the left column of the left graph (explicit career bias measured at the beginning) are more tightly grouped than are the points in the left column of the right graph (*implicit career self-concept*). We quantified these as the variance in the post minus pre (post-pre) scores - 0.07 for explicit declarations versus 0.42 σ^2 for implicit bias. The second visually obvious feature is that the scatter in the slopes of the lines (beginning to end change) is much larger on the right than it is on the left. changed more from the beginning to the end of the semester than did explicitly declared *career bias*.

Consistent with this variability in slopes, the relationship between post-pre changes in *explicit career bias* and implicit *career self-concept* was weak to moderate, yet significant (r=0.316, p=0.005, Figure 4).

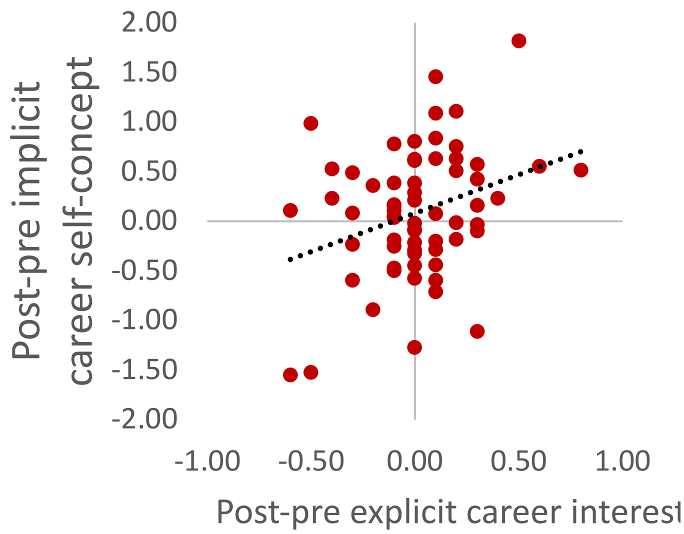

Figure 4: There is a moderate positive correlation between semester-long changes in implicit *career self-concept*, and explicitly declared *career bias*.

There was a trend toward significant difference by gender in bias changes. In the case of *explicit career bias* there was a trend toward men gaining more engineering *explicit career bias* than women (p=0.09). This trend held true also for implicit *career self-concept*, though not at nearly the level of statistical significance. This was not due to starting values for explicitly declared career interests which were not different between men and women. There were no statistically significant differences by ethnicity.

We further asked students who felt their career interests had changed to explain what they thought the reason was for that change. We coded the responses (Table 2), and found that the two most commonly cited reasons for changes in career interests were (a) the skills-based second-year design class with which this study was associated, and (b) perspective that they've gained over time, sometimes through lived experiences. It is worth noting that in our BME curriculum every second-year course is offered in both the Fall and Spring semesters, and thus the students in this class only had in common this one design course, not an entire set of BME courses.

Reason given for their perceived change in career interest	Count
This design class	10
Perspective gained over time	9
Other BME classes	5
Biomechanics as a specific class	2
Peers	1
Undergraduate research experience	1

Table 2: Coded responses to a question on why their career interests may have changed over the past semester.

Relationship to *self-efficacy*

We found small but significant changes in all areas of self-efficacy over the course of the semester ($p<0.02$ in all cases by paired t-test, Table 3).

We found that a student's explicitly declared degree of interest in medicine correlated positively and significantly with one domain of *self-efficacy*: an ability to overcome obstacles ($p=0.01$). It was nearly significantly correlated with an ability to learn new things ($p=0.06$). In contrast, students' explicit *career bias* toward engineering did not correlate significantly with any aspect of *engineering design self-efficacy*.

Aspect of *self-efficacy*	p	$\overline{post - pre}$
Identify a need	<0.001	+1.08
Research a need	0.002	+0.87
Develop solutions	<0.001	+1.56
Select a solution	<0.001	+0.90
Implement a solution	<0.001	+1.40
Evaluate the solution	<0.001	+1.42
Document	<0.001	+1.27
Communicate	0.001	+1.08
Overcome obstacles	<0.001	+1.05
Learn new things	0.020	+0.50
Empathize	0.011	+0.68

Table 3: Post-pre changes in aspects of the *Ability* domain of *engineering design self-efficacy*. In yellow are three aspects added by the investigator.

Students' explicit bias toward engineering or medicine (that is, the normalized difference between their self-concept scores in those two areas) was significantly correlated with only one area of *self-efficacy* – the ability to overcome obstacles. In contrast, *self-concept* measured by implicit bias was not significantly correlated with any measure of *self-efficacy*. This suggests that while explicit and implicit measures of *self-concept* in part reflect the same construct, they are not identical. Further, the data suggest that the career leanings of biomedical engineering students have little association with *design self-efficacy*.

Discussion

These data on BME students compare favorably to previous findings showing that engineering students and practicing engineers, unlike persons in other domains, are relatively unbiased toward their own choice of career [12]. While this appears to hold true, overall, of BME students as well as of others, it is also true that these biases vary enormously from student to student in BME; some have very strong bias toward either engineering or toward medicine.

On average the students in this study were unbiased in their career self-concepts, showing neither a strong bias toward engineering nor a strong bias toward medicine. While it is tempting to view a lack of bias toward engineering as a negative, it could reflect the pre-existence among students of a *clinician-engineer self-concept*. In fact, we find in the pre-course surveys that students declared moderate interest of 5.2 ± 0.4 in a clinical career, and 7.3 ± 0.2 in an engineering career. That is, they are interested in both careers simultaneously, and this results in a low bias score. BME as a choice of major makes sense as the natural intersection between these fields.

A potentially concerning finding is the observation that men, but not women, appeared to gain in explicit career bias toward engineering, while for women it remained unchanged. While these data didn't reach the level of statistical significance, it bears attention and further exploration given the progressive loss of women from graduation to engineering careers [13]. It is perhaps doubly concerning that this trend was found among BME students – a field generally viewed as one of a few engineering fields preferred by women compared to others [14]. It is possible that the design course which was the intervention here only has such an impact on men. Indeed, men are more likely than women to perceive "building" as an essential component of engineering design [15].

There are notable overlaps and differences between this work and other studies of engineering identity. Most studies of engineering identity seek to isolate factors that are associated with identifying one's self as an engineer. Further, they are identities "in the moment," rather than being tied to a career choice. However, among the factors that have been found to be predictive are measures of self-efficacy, including an ability to overcome obstacles [16], [17]. Future work may seek parallels between such measures of engineering self-identity, and the career biases measured here.

We found that pre-to-post course measurements of implicit career bias changed considerably more than did explicit measures. These data consistent with findings of others showing that implicit attitudes are more labile or change more quickly than do explicit attitudes [18]. The reason for this is unclear, but implicit attitudes may be more strongly influenced by recent events than are explicit attitudes.

We may be observing a reflection of a slow shift during BME students' college years away from medicine and toward engineering, even though on a semester-by-semester basis students and their instructors may not perceive it. This is consistent with previous work showing a 9% per year "attrition rate" of BME students' self-declaration of being pre-med [1].

Self-concept has been identified as a predictor of motivation to aspire to a particular career [19] and potentially as an academic goal in and of itself [20]. While they are correlated, and while we would have assumed them to measure the same thing, *explicit career bias* and implicit *career self-identity* may be measuring different time frames because of their relative temporal stabilities. Thus, studies of *explicit career bias* and *implicit career self-concept* may prove valuable in several ways. First, they may shed light on gender differences in engineering career outcomes. While the literature on loss of women from engineering and engineering careers is extensive, it is arguably lacking in defining particular curricular elements that promote persistence of women into engineering careers. Capturing career bias and self-concept longitudinally through undergraduate programs may help reveal these details.

Second, measures such as these may help us determine what curricular elements guide students in their choices of career pathways. In this study we found that while there are several reasons that students shifted in their explicit or implicit career bias, a hands-on, skills intensive BME design class may have an outsized influence on students steering toward careers in engineering as opposed to medicine.

Finally, and related to both of these, if implicit career self-concept is more sensitive to recent events, it may be especially helpful in narrowing interventions to specific semesters of study or to specific curricular elements. For example, our data are consistent with previous work showing that *engineering design self-efficacy* improves during both project-based and skills-based design courses [7], [21]. Courses such as these may prove to be strong mediators of change in persistence to engineering careers, but it is unknown whether the effects of such learning experiences persist over time. The two measures of self-concept presented here could therefore teach us much about the durable effects of teaching and learning on career persistence.

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