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Clinician-Engineer Self-Concept in Biomedical Engineering students and Its Relationship to Race, First-Generation Status, and Mode of Delivery

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Introduction and abstract

Retention, recall, comprehension, and measurable skills are mainstays of the scholarship of teaching and learning, and yet they represent only a fraction of what engineering educators hope to achieve through education. The development of self-efficacy, for example, is a common goal and is often measured as a psychological construct. Less commonly measured constructs that are nonetheless commonly valued by educators are the development of *creativity*, perseverance (*grit*), and *self-concept*.

Self-concept is particularly interesting in the context of career goals. Biomedical engineering undergraduates are often drawn to clinical practice rather than to careers in engineering – 54% according to one study [1]. This implies an equivalent *self-concept* among BME majors as clinicians and as engineers. Indeed, this has been shown to be the case in previous work [2]. These data sets were small, however, and they left unknown how malleable *self-concept* may be over the course of a single semester, for different groups, or in different learning environments.

We performed a multi-year study of BME students' career *self-concept* as engineers and as clinicians. The goal was to determine (a) if career self-concept, either in the absolute sense or in its change over time, differed by demographic group; and (b) whether career *self-concept* was influenced by learning modality. The pedagogical changes brought on by the COVID-19 pandemic served as a natural experiment for the latter.

Over the course of six contiguous semesters spanning Fall 2019 to Fall 2021 we measured absolute and relative *self-concept* (engineer *versus* clinician) from 333 students via explicit declaration, and via an implicit attitudes test (IAT). The IAT is a psychological test that relies on repeated measures of response latency in a subject's association of two concepts – in this case, between the concepts of self and other, and the concepts of clinician and engineer. We interpreted the resulting measure of implicit bias as a measure of *career self-concept*.

The data suggest that career *self-concept* is, on average, remarkably stable with modest and oftentimes insignificant changes over the course of a single semester, and with few or no trends across the pre-, mid-, and post-pandemic timeframe. It varies greatly between individual students, however, and can change greatly over the length of a single semester, though students gaining in engineering career *self-concept* are balanced by students losing in engineering *self-concept*. We identified differences in *self-concept* change between racial/ethnic groups and between first-generation and continuing-generation students. We also found that students cannot accurately judge their own changes in engineering 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 [3]. These included CAD, microcontrollers, basic circuits, 3D printing, subtractive approaches to prototyping (depending on semester), and digital image analysis. The course culminated in a closed-ended team-based design project with a physical prototype due at the end.

Students would have taken 0 to 3 courses prior to the design course in question. This is because students at our institution enter their major after their first year, and they can take the design course (and 4 other second-year BME courses) in either the Fall or the Spring semester.

Both explicit and implicit measures were delivered to students through an Qualtrics online survey. This survey was delivered before the second class meeting of the semester, and again in the week of final exams. Students received one-point of extra credit for completing the finals week survey. The survey included:

1. 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?

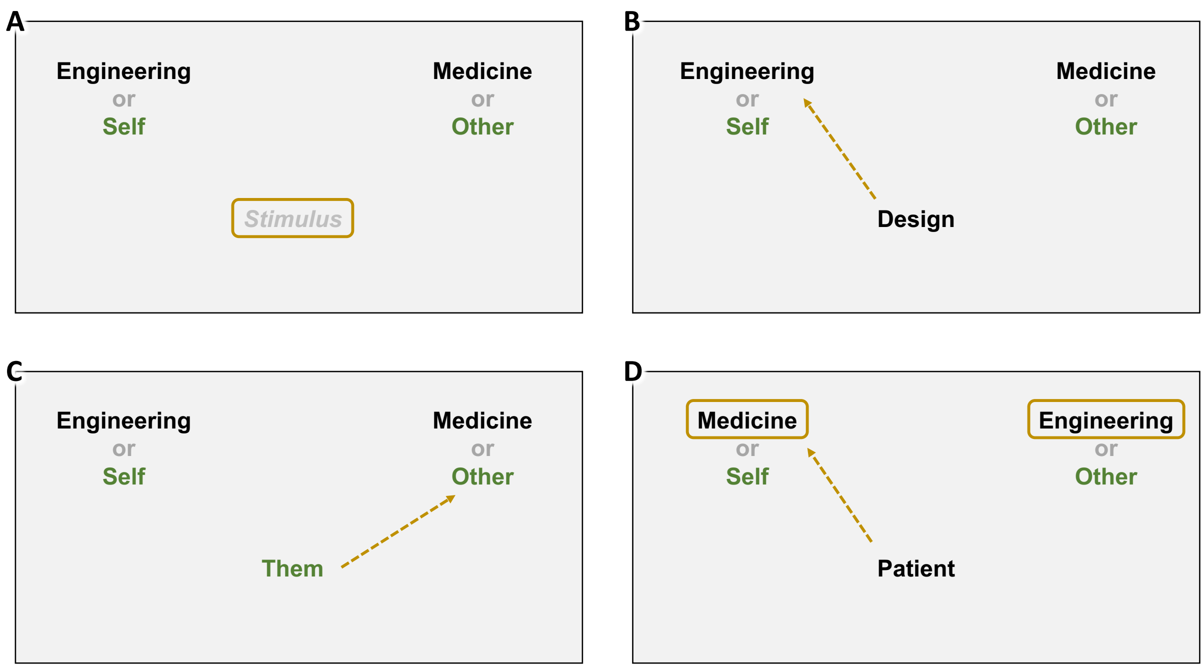


Figure 1: Illustration of the Implicit Association Test (IAT). A: The stimulus is displayed in the center of the screen, and the user presses a key on the left or right-hand side of the keyboard to sort that stimulus into the appropriate category. B: In this example, the user would press the left-hand 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.” Reprinted from our previous work [2].

2. A *career self-identity* Implicit Association Test (IAT) that we designed for Qualtrics using the iatgen tool [4].

   The 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 concepts of self and other, and the concepts of clinician and engineer. In the IAT, participants categorize a series of stimuli that appear 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 another 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 [5].

Data were organized using Excel (Microsoft), and statistical analysis was performed using SPSS (IBM). Statistical tests are specified in the text. For expressing effect sizes we use the conventions of Cohen [6] and of Gignac and Szodorai [7].

Results

We began with data pooled from 6 semesters of the design course. This resulted in 333 unique pre-semester responses that were complete in all respects, and 267 complete end-of-semester responses that also had matching pre-semester scores (see Table 1).

Table 1: Demographics of the multi-semester sample

		N
Gender	F	171
	M	96
IPEDS	Asian	64
	Black or African American	10
	Hispanic	14
	Multi-Race	15
	Non-Resident Alien	2
	Race and Ethnicity Unknown	17
	White	145
First-gen	No	239
	Yes	28

Biomedical Engineering students simultaneously hold self-concepts as engineers and as clinicians

As shown in Figure 2, when students were asked in separate questions their interest in becoming an engineer and their interest in becoming a clinician, students showed an overall bias in interest toward being engineers.

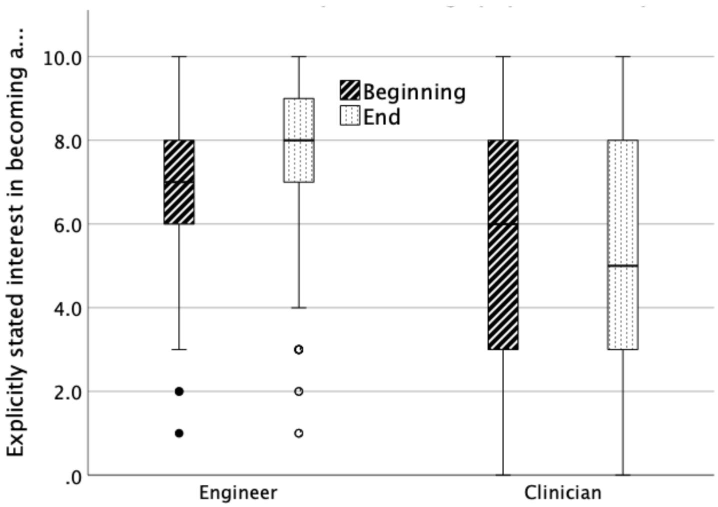


Figure 2: Students' explicitly declared interest in becoming engineers and in becoming clinicians measured at the beginning (Pre) and end (Post) of the design course.

These should not be interpreted, though, as a lack of interest in becoming clinicians. Note that on a 0-10 scale, students at the beginning and end of the semester scale their interest in becoming clinicians at 5.3 ± 0.2 (mean ± sem), indicating a *moderate* interest, not a lack of interest. This moderate mean is due to a bimodal distribution of students who are as interested in being clinicians as in being engineers, and students who are explicitly uninterested in becoming clinicians (Figure 3).

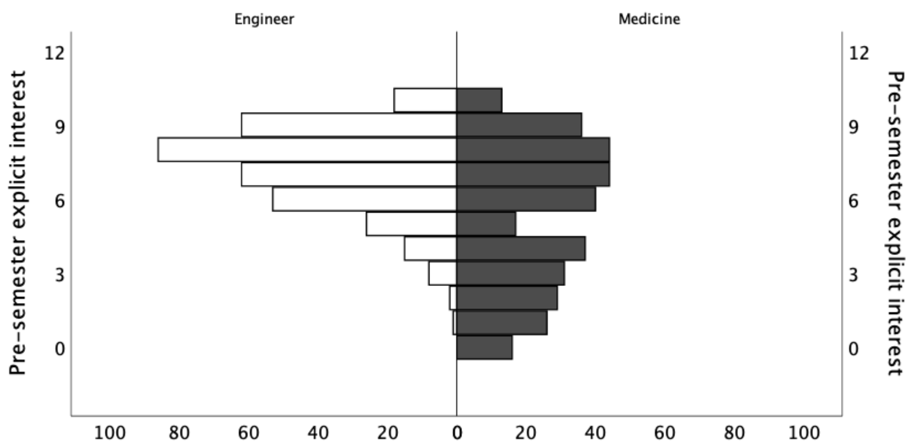


Figure 3: Histogram of pre-semester explicit interests of students in becoming engineers (left), and of becoming clinicians (right).

Univariate ANOVA was used to determine if there were any significant demographic factors among those listed in Table 1of beginning or end-of-course interests in becoming an engineer or becoming a clinician. No significant factors were found. The lowest p-value was 0.187 for race/ethnicity as a factor in beginning-of-semester interest in becoming a clinician.

Career bias as a measure of career self-concept

We can use these data in a different way, posing the question "are individual students biased more toward being engineers or toward being clinicians?" The implicit association test *only* returns a bias, in this case engineering relative to medicine, in the form of an effect size, *d*. We therefore calculated an explicit career bias by subtracting each student's "interest in becoming a clinician" score from their "interest in becoming an engineer" score and dividing by 10. We divided thus because (a) their original scores were on a scale of 0-10, and (b) to place it on a similar scale to the result of the implicit association test.

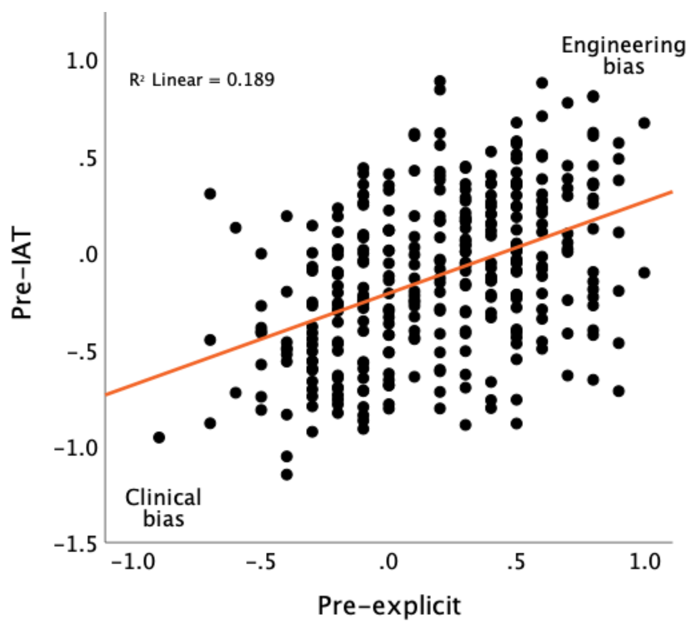


Figure 4: The implicit career bias (pre-IAT) is correlated with a measure of explicit career bias (pre-explicit) when measured at the beginning of the semester. Each data point represents one student.

We refer to these two bias measures as the *implicit career self-concept* and the *explicit career self-concept*.

It is obvious by inspection of Figure 3 that the bias on average should be toward engineering. Indeed, the explicitly measured career bias at the beginning of the semester was on average 0.19 ± 0.02, with the positive value indicating a bias toward engineering.

Explicit career *self-concept* and implicit (bias) career *self-concept* are related to one another with a medium to large effect size *r* of 0.44. This implies that they are measuring the same construct, or at least closely related constructs.

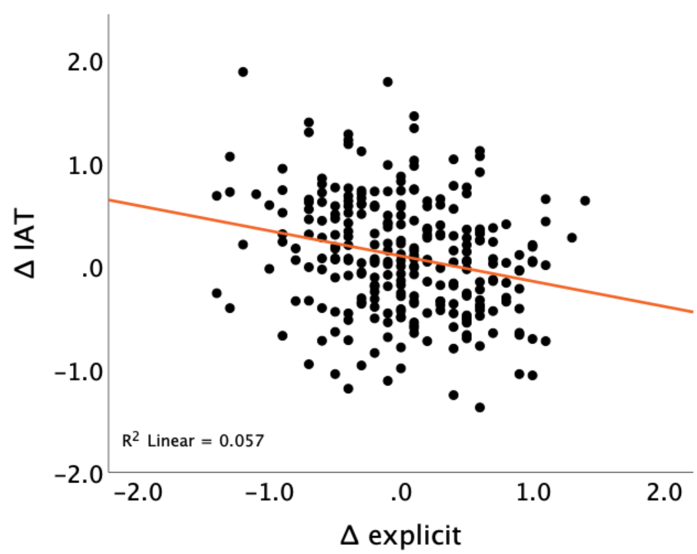


Figure 5: The semester-long changes in implicit and explicit career *self-concept*s were negatively correlated. Each data point represents one student.

Changes were determined on a per-student basis over the span of a single semester, beginning (pre) to end (post). A positive delta in bias means toward engineering. Surprisingly the semester-long changes in career *self-concept* were negatively correlated. That is, an increasing explicit career *self-concept* predicted a decreasing implicit career *self-concept* with a weak to moderate effect size of *r* = -0.238. This is because students beginning and end of semester IAT bias scores were weakly negatively correlated, suggesting that some students who were implicitly biased toward engineering at the beginning of the semester became less so.

Paired t-test was used to determine if students' career *self-concept*s changed over the course of a semester. Indeed, students' *implicit* career *self-concept*s changed by an average of 0.1 ± 0.04 (*p*=0.009 two-sided). In contrast, explicit career *self-concept* remained unchanged (0.03 ± 0.03, *p*=0.353). To put this on a more intuitive scale, the above change of 0.1 in the implicit measure is comparable to a change of 1 on the explicitly declared interest in engineering or clinical work.

First-generation status is a factor in implicit career self-concept

We used analysis of variance to determine what factors might be associated with changes in explicit or implicit career *self-concept*. Among the several demographic possibilities (Table 1), only first-generation status (as opposed to continuing-generation status) was a significant factor (*p*=0.011). First-generation students on average showed little change in their implicit *self-concept* toward engineering as opposed to clinical careers compared to their continuing generation peers who demonstrated slight increases (-0.002 compared to 0.1). Explicit *self-concept* showed a similar trend, but that trend was not significant.

There were no significant differences between genders or race/ethnicity in semester-long changes in *self-concept*.

Individual changes in self-concept can be substantial and these changes vary by race

Table 2: Descriptive statistics for semester-long changes in implicit and explicit career self-concept

	Minimum	Maximum	Mean	σ
Δ implicit	-1.37	1.88	.09	0.57
Δ explicit	-1.40	1.40	.02	0.55

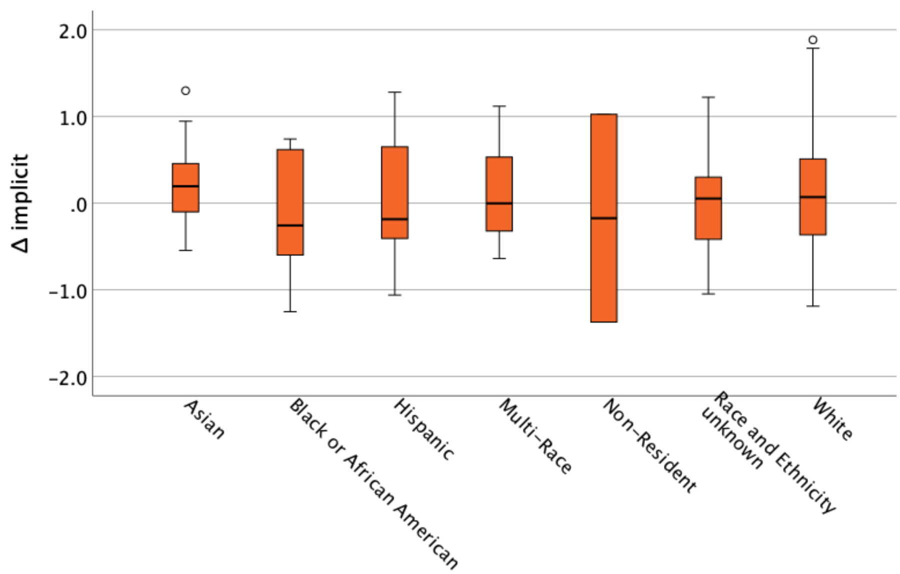
Sample means, particularly when they are normally distributed about ~0 as they are here, can obviously mask even *large* changes on the parts of individual students. In fact, looking at the range of semester-long changes in self-concept shown in Table 2, we see that the maximum range of changes in explicit career *self-concept* (±1.4) is 70% of the maximum theoretical range, and yet the mean is close to zero. These changes are better expressed and explored as variances.

To compare groups we used a Levene test to check for homogeneity of variances between groups. Variance of the change in career *self-concept* was the same for both first-generation status and for gender. This suggests that these groups experienced about the same range of changes in their explicit and implicit career *self-concepts* over the course of the semester.

For IPEDS race and ethnicity groups homogeneity of variance was *not* satisfied in the implicit domain (p=0.001), suggesting that some racial or ethnic groups experienced smaller semester-long changes in implicit career *self-concept* than did others. Specifically, Asian students evidenced substantially smaller variance in change than did other groups (Figure 6).

Student self-reports are poor predictors of measurable change

Students were asked at the end of the semester whether they believed their career interests had changed over the course of the semester, and if so, to what they owe the change. These students did not differ from students who felt that their career interests had not changed, neither in mean



IPEDS	σ^2
Asian	0.160
Black or African American	0.453
Hispanic	0.485
Multi-Race	0.324
Non-Resident	2.872
Unknown	0.415
White	0.347

Figure 6: The variance of semester-long changes in implicit career self-concept depends on the IPEDS racial and ethnic group. Left: A box plot of changes in implicit career self-concept. Right: Variances associated with each group.

difference (p=0.451 and p=0.278 for explicit and implicit change, respectively) nor in variance of change of career *self-concept* (p=0.322 and p=0.085 for explicit and implicit change, respectively). Put another way, students do not successfully predict whether their career self-concept changes.

We examined the free response text to learn to what students owed these changes. The most common words in the corpus of "If you feel that these interests changed over this semester, to what do you attribute that change?" were: classes (15 instances); engineering (14); BME (13); engineer (12); like (9). The two most common themes that emerge upon reading the comments are (a) many students found the engineering content and skills of their second-year, major-specific classes to be more engaging and relevant than what they experienced previously, and that helped inform their direction; and (b) some cited the stress, difficulty, and perceived weak grades as a factor.

Pandemic teaching had no impact on career self-concept, but there is a trend toward smaller semester-long changes

The institution where this study was conducted changed its mode of instruction during the pandemic. Fall 2019 and prior the class was taught almost entirely in-person, with several training workshops on tools for fabrication, and a major hands-on project at the end. Spring 2020 was moved entirely online mid-semester. The following academic year (Fall 2020-Spring 2021), lecture was conducted entirely online, and only limited in-person workshop opportunities were available. The project likewise was limited in scope and conducted mostly outside the classroom or workshop. Instruction returned to a new normal (flipped classroom with extensive workshop learning opportunities) in Fall of 2021. We found no statistically significant differences between semesters in terms of absolute scores (explicit or implicit) by multivariate analysis of variance, or in the distribution in changes of self-concept (Figure 7) by Levene.

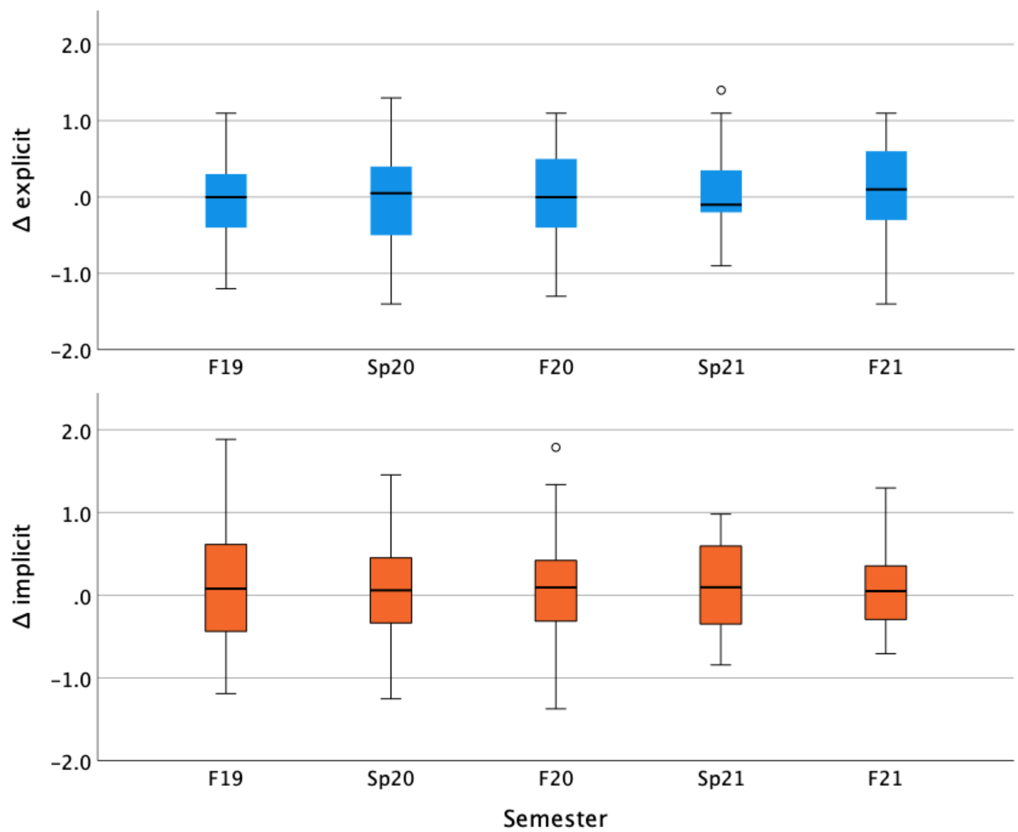


Figure 7: Box plots showing how changes in *self-efficacy* (explicit top, implicit bottom) vary by semester. No differences or trends are evident.

Discussion

This multi-year study adds nuance and precision to previously published work on engineering career self-concept [2]. We hypothesized that an intensive course to develop engineering skills would lead to stronger engineering *self-concept*. While the change in engineering self-concept measured by IAT were significant, they were small. This is still of interest because we have no idea of the rate-of-change of career *self-concept*. This manuscript establishes a baseline for what kinds of changes we might expect to see and on what timescale.

It was found previously reported that BME students specifically [2], and practicing engineers generally [8], are relatively unbiased in their career *self-concept*, showing neither a strong bias toward engineering nor toward medicine It was also reported that these biases vary enormously from student to student, with some having a strong bias toward engineering and others toward medicine. It was proposed nonetheless that BME students generally hold a join *clinician-engineer self-concept*.

The present work, conducted at considerably larger scale and across multiple years, confirms those findings. Students begin the semester explicitly interested in becoming engineers (7.20±0.09), and less but still substantially in becoming clinicians (5.3±0.2). This is backed by implicit measures of bias (self-concept) that likewise show a degree of equivalence among second-year BME students in their career *self-concepts*, meaning that they are unbiased in that regard. 39% of the students studied here had dual *self-concepts*.

Unlike previous work, we found no differences in *self-concept* or changes (gains or losses) in *self-concept* between genders. Nonetheless, we did find that changes in career *self-concept* differ across some demographic groups.

First-generation students do not experience the gains, small though they were, in implicit career *self-concept* over the course of the semester that were experienced by their continuing education peers. Likewise, the magnitude of change in career *self-concept* was significantly lower among Asian students than among other racial and ethnic groups, suggesting a greater stability in *self-concept*. We cannot say what is "better" – a stable career *self-concept*, or one that is more malleable, but the existence of these biases may be cause for concern and merit further study. Longitudinal studies may shed light on this question.

Of interest, the changing instructional modes during the COVID-19 pandemic – first to wholly online instruction, then to hybrid instruction with changes to student projects, and then a return to "normal" (reported in part in [9]) – had no discernable impact on engineering career self-concept. This may be a real-world test of Clark's famous assertion that "there are no learning benefits to be gained from employing any specific medium to deliver instruction." [10] It is also worth noting that a significant fraction of the variability in STEM career aspiration has been found to be attributable to authentic project-based learning [11]. In the present class, the projects before, during and after the pandemic could not be truly described as authentic in that they lacked a client, and the addressed an already solved problem. Thus, while the medium changed during the pandemic, a potentially more impactful aspect of teaching and learning did not.

Students were unable to accurately judge their own changes, whether toward being an engineer or toward being a clinician, over the course of a semester – not in the explicit domain, nor in the implicit domain. We found no differences in either the mean change or in the distribution of changes of these measures. It isn't a given, however, that student self-assessments are errant; the accuracy of student self-assessments have been known for some time to depend on the level of the course, the area of study, and the quality of the study or instrument design [12]. In this instance we suspect that the informal learning in this classroom setting led to memory bias – a difficulty in accurately recalling information about their own behaviors or experiences. This can lead to inaccurate self-reports of past attitudes [13]. Social desirability bias – a tendency to respond in ways that respondents believe will be viewed favorably by others – is another possibility when engineering students are being asked to respond about their career preferences, but has been suggested by others not to be much of a factor in student self-reports of these sorts [14].

Regardless, the things students name as being influential in their perceived change in career interest – experience gained in their gateway BME courses, and concern for their personal academic performance – highlight the importance of these classes in promoting persistence within the major and to their desired career. If their explicit and implicit career self-concept remains unchanged, and yet their gateway courses convince them to head in a different direction, what does this incongruity mean for their satisfaction and for their job prospects?

Limitations and future directions

In addition to the limitations of class format (non-authentic projects, for example), the implicit attitudes test comes with caveats and concerns. The literature here is extensive, and a review is beyond the scope of this paper, but as outlined in [15], "there is no basis to expect strong unconditional relations between implicit bias and behavior," implicit bias is less stable over time than explicit bias [16], and the context of the measurement (an assignment in a class, in this case) matters in determining the outcomes obtained from the IAT. Nonetheless, our data are bolstered by collecting clearly corresponding data in the explicit domain; that is, we found a correlation between explicit and implicit career *self-concept* at the beginning and end of the course. Others have noted that implicit and explicit measures tend to be related and correlated to one another when there is clear conceptual correspondence [17]. Thus, we feel that these concerns are minimal in the current context.

We are also limited by a lack of longitudinal data. What becomes of these students over time? Is engineering career self-concept related downstream to career decisions? How does engineering career self-concept change over time? What experiences or classes are associated with changes? Perhaps more intense experiences than what is experienced in a typical classroom will cause measurable changes, and perhaps measures such as these will help determine where changes can be made. Since all the measurements reported here were taken in students' second years of undergraduate BME study, there is obvious room for study.

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