Who Goes where: patterns in academic field switching of successful college graduates

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We examine patterns of students switching into and out of colleges, STEM/non-STEM fields, and majors within fields, examining the impact of both discipline and demographics. Our data include over fifteen years of student records, with over 22,000 students graduating with an identifiable degree. Restricting the analysis to graduates removes issues of readiness and retention, instead focusing on issues of environment and pathways. We find statistical significance in switching rates of students in colleges of engineering, computer science and applied science and "paths" between colleges that students are more likely to follow as they switch majors. Correlation between persistence within a program and student demographics — gender, ethnicity, and deaf/hard-of-hearing status — is strongest in STEM colleges of engineering, computing and applied science and non-STEM colleges of health science and liberal arts. Connections are seen between colleges of engineering and applied science and between biology (within the College of Science) and non-clinical health sciences, and large-scale trends in switching are seen to have changed over time.

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I. INTRODUCTION

The underrepresentation of students and employees in STEM disciplines is well documented, with undergraduate enrollment across the country as low as 14% [5] and declining [3]. Studies to date have focused on three critical points of the process: entry, retention, and graduation. Enrollment is affected by potential employment opportunities and compensation [12] and degree of social and cultural capital [21, 22]. African American, Latino/a American and Native American (AALANA) students and non-AALANA women comprise 70% of the U.S. college student population yet are less likely to choose majors [16] and receive degrees [8] within STEM disciplines than white men. 48% of students initially enrolled in a bachelors program and 69% enrolled in an associate's degree program within STEM fields leave the discipline or their institution before graduation [6]. Persistence of men correlates with performance, whereas for women persistence correlates with academic environment [2, 17]. Degree completion and persistence rates are also consistently higher for white students than students of color [5, 6, 14, 20].

Patterns of student *switching* between programs or majors do not appear to be due to lack of preparation or STEM abilities [11] nor academic difficulty [12]. Rather, changes in major correlate with dissatisfaction with introductory courses and perceived low level of job/money-making opportunities. *Changing* majors also correlates to higher graduation rates [13], suggesting that students that switch majors are not unprepared for the academic rigor of postsecondary education. Students tend to switch into majors with people who "look like them" [2] with women, in particular, more likely to leave STEM majors [4, 7, 10]. Switching, therefore, is not undesirable in and of itself, but differential switching (between gender, race, etc.) can be an indicator of hostile environment.

White women and ethnic minorities change major more frequently, both in general [12] and from within STEM fields [4, 6, 9, 14, 20] than white men. The biological sciences are the source of the largest fraction of non-AALANA women and AALANA students switching majors [9]; engineering is the source of the plurality of male switchers. Orr et al. [15] looked at the differential between students entering and leaving mechanical engineering, finding AALANA students leave more often than they enter, whereas non-AALANA students enter and leave in approximately equal proportions. When students leave STEM fields, there is a high probability that they subsequently declare a business (or business-related) major [2, 4]. An exception is engineering; original engineering majors preferentially switch into computer science fields [7]. Because switching studies require significant longitudinal data most (e.g., 6, 8, 11, 14, 17, 18), even extremely recent ones (e.g. 2), involve students that have graduated before 2010. There is little work comparing the evolution of student switching patterns over time, knowledge that is critical to evaluating current STEM initiatives and formulating plans for future programs to attract students.

This study focuses on a macroscopic view of switching: ignoring for the most part specific programs or majors and instead analyzing students that graduate the institution for changes across fields, defined as STEM vs. non-STEM, or colleges, which define broad disciplines (science, engineering, computing, etc.). Specifically, we ask **what are demographic or programmatic features of students that switch programs en route to graduation.**

II. INSTITUTIONAL CONTEXT

The data for this study consist of student records from 2002-2018 from a technical institute in the northeastern United States. $22,225$ students received an identifiable undergraduate degree and are included in our study. Excluded are $8,457$ students that received a graduate degree (which obscures the undergraduate degree in our data set) and $13,169$ that left without receiving a degree. The data contain the major (each term), demographic information on gender, race/ethnicity (restricted to African American, Latino/a American, Native American or other), and deaf/hard-of-hearing status (the institute is home to a technical institute for the deaf). The binary reporting of gender is imposed by the institute which, for the time period under study, constrained students to indicate either "male" or "female." Results are thus insensitive to the more nuanced and fluid understanding of gender that has evolved. Similarly, student records identifying race/ethnicity are limited to a binary (AALANA — African-, Latino/a, and Native American — or White/other). Doing this, and excluding completely other important ethnic identities (e.g. Asian) is a weakness in this study.

College	Sample Majors
Engineering	Electrical Engineering, Mechanical Engineering, Chemical Engineering
Computing	Computer Science, Computing Security, Game Design, Software Engineering
Appl. Sci.	Electrical Engineering Technology, Mechanical Engineering Technology
Science	Physics, Math, Chemistry, Biology
Non-clin. Health Sci.	Biomedical Sciences, Dietetics and Nutrition, Exercise Science, Physician Assistant
Non-STEM	Communication, Psychology, Public Policy, Economics, Criminal Justice

TABLE I. Representative majors for four STEM colleges (Engineering, Computing, Applied Science and Science), Non-clinical Health Sciences and four non-STEM colleges (combined into a single unit).

Degrees are earned in one of nine colleges: computing, engineering, applied science, science, business, art/design, liberal arts, health science, and non-clinical health science. Importantly, all students apply to specific programs within the Institute and thus declare a major upon enrollment. Changing majors is facilitated by advisors who help students navigate the process, which can impact the anticipated time to graduation. Representative degrees are shown in Table I.

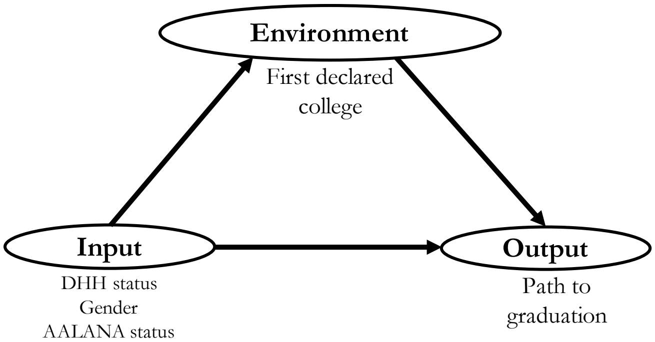

FIG. 1. A schematic of Astin's Input-Environment-Outcome model, adapted from Astin (2012). Arrows show directional connections between model variables.

	AALANA	Male	DHH	Decade
STEM Colleges				
Engineering	$\mathbf{0.122}^{\dagger}$	0.025	$-\mathbf{0.253}^{\dagger}$	$\mathbf{0.040}^{**}$
Computing	$\mathbf{0.089}^{\dagger}$	$\mathbf{0.055}^{\dagger}$	-0.009	0.009
App. Sci.	$\mathbf{0.072}^{\dagger}$	0.009	$-\mathbf{0.084}^{*}$	$\mathbf{0.022}^{*}$
Science	0.036	-0.015	-0.054	$\mathbf{0.112}^{\dagger}$
NC Health Sci.	0.035	0.025	$-\mathbf{0.268}^{**}$	0.052
Non-STEM Colleges				
Health Science	$\mathbf{0.169}^{\dagger}$	0.009	0.061	$\mathbf{0.044}^{*}$
Business	0.027	0.026	-0.056	0.015
Liberal Arts	$\mathbf{0.062}^{*}$	$-\mathbf{0.084}^{\dagger}$	-0.025	0.011
Art/Design	0.019	0.032	$-\mathbf{0.215}^{*}$	$\mathbf{0.159}^{\dagger}$

TABLE II. Model coefficients for full 2002-2018 data, representing persistence for each group. Coefficients that represent statistically significant differences in persistence are **boldface** and marked ($^{\dagger}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.)

III. THEORETICAL FRAMEWORK

We ground our study in Astin's Input-Environment-Outcome (IEO) theory [1]. Illustrated in Figure 1, this model portrays connections between input, environment, and outcome as directional arrows. Inputs are "personal qualities the student brings to the educational program," (gender, AALANA status, and deaf/hard-of-hearing – DHH – status). Environments are "the student's actual experiences *during* the educational program," in our case characterized by the institute's internal colleges. Our outputs are the students' graduation field and its relation to their incoming program choice. To probe the time-dependence on large time scales we introduce the decade (2002-2010 and 2010-2018) of graduation as a binary environmental factor, dividing our data roughly in half ($N_{<2010} = 10,015,\ N_{>2010} = 12,210$).

We define *persistence* P as a student receiving a degree from the same college they declared upon entering. This definition preserves the sense of disciplinary cultural consistency that is embodied by the distinct college. We construct a multivariate regression model of the form

$$P = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_i x_i, \qquad (1)$$

where the x_i are the various input and environment factors, including decade. Model coefficients are shown in Table II, with statistically significant coefficients in boldface. Coefficients represent deviations of the mean; the single model is applied to all data and accounts for interaction effects (e.g. impact of being both "Male" and in "Computing.") The data show moderate heteroscedasticity; more complex nonlinear models could be the focus of future research.

IV. RESULTS

A. Differences by student demographics

Correlation between persistence and non-AALANA status is strongest in the STEM colleges of engineering, computing, applied science and in the non-STEM colleges of health science and liberal arts. In all of these cases non-AALANA students persist at rates higher than that of AALANA students. Colleges of computing and engineering show significant differences in persistence rates between students of different genders, with the men students out-persisting women students. Three non-STEM colleges (business, liberal arts and arts/design) show significant differences by gender. In the college of liberal arts, women (a majority of students in that college) are more likely to persist than men. DHH status is significantly correlated with persistence in three of the STEM colleges (engineering, applied science, non-clinical health science) and one non-STEM college (art/design), with hearing students more likely to persist than their DHH peers.

B. Differences across time

Persistence patterns have changed over time, as seen in the rightmost column in Table II. In all colleges, successful undergraduate students prior to or in 2010 were more likely to maintain their original college than students who graduated after 2010. This is significant in three STEM colleges (engineering, applied science, science) and two non-STEM colleges (health science, art/design). It is important to recall that all of these students subsequently graduated with undergraduate degrees after switching major.

We find that students are switching majors at higher rates in the last nine years than years prior (yet still successfully earning undergraduate degrees). Five colleges have statistically significant variation in college switching pre- and post-2010. All of these cases show *increased* switching after 2010 as compared to the switching rates before 2010. The colleges for which this increase is significant are the college of engineering, applied science, science, health science, and art/design. The college of science is the only college for which demographics have no intersection with the temporal switching dependence. The other four colleges which show significant differences in pre- and post-2010 switching rates also show significant differences in at least one demographic.

C. Difference by STEM/non-STEM field and discipline

Students who originally declare within STEM/non-STEM colleges persist in their field $92\%/96\%$ of the time, and persistence does not vary greatly across colleges within each field. The majority of students who leave a non-STEM college do so for another non-STEM college. In STEM, however, only students leaving colleges of engineering and science do so (on average) for another STEM college. Students that leave colleges of computing, applied science, and non-clinical health science tend to do so for non-STEM colleges.

Distributions of the paths between colleges for students that switch can be seen in Table III and reveal distinct connections between colleges. If students moved evenly between the five remaining colleges, distributions between all origin and target colleges would be an average 20%. We first note that students who initially declare a major in non-STEM switch fairly evenly between the other five colleges, with the exception being a low percentage into Engineering and a higher percentage into Applied Science. Applied Science houses many Engineering Technology programs, and so the narrative is that 40% of non-STEM switchers desire some form of engineering, which they satisfy in Engineering Technology programs. Engineering students who switch tend to go mostly to computing and applied science, with very few switching into non-clinical health science and non-STEM. Finally, the switching from science into non-clinical health science and engineering to/from applied science is distinct.

In looking at the connection between non-clinical health science and the college of science, we note a distinct connection between "bio-X" majors (biology, biochemistry, bionformatics, and biotechnology/molecular bioscience). Of the 40% of students who entered the college of non-clinical health science after leaving the college of science, 83% are students who originally declared a major that began with the "bio" prefix. Similarly, of the 57% of students who began in non-clinical health science and switched to science, 75% earn a degree in either biology or biochemistry.

A similar relationship is found between the colleges of engineering and applied science. In particular, a large proportion of "engineering exploration" majors switch into programs within the college of applied science. The engineering exploration major acts as a springboard to allow undecided engineering students to choose which of several engineering fields is their preference. 70% of initial engineering exploration students remain in the engineering college, with 13% in fact switching out of engineering and into applied science. (The next largest path for engineering exploration declarers is to the computing and science colleges, 4% each.)

V. INTERPRETATION OF RESULTS

We interpret Table II in the context of the IEO model, the 9x4 matrix combining demographics, college, and decade. These combinations showed statistically significant differences ($p < 0.05$) in persistence rate between members of opposite demographic groups. In STEM, 50% of the combinations were significantly different, and in non-STEM colleges, only 37.5% of the combinations differed across factors.

STEM colleges show more differences across factors than non-STEM colleges. This is consistent with other works; STEM programs show more differences in persistence by demographic than non-STEM programs. Another possible explanation is the technical focus of the institute may contribute to the overall non-STEM persistence rates. The availability and wide range of technical fields, as well as the work experiences afforded students affiliated with the institute, may be the attraction for some fraction of the non-STEM switching students who ultimately leave non-STEM.

We see few differences in persistence by college based on gender, with only colleges of computing and liberal arts showing significant differences. In the computing college men students are more likely to persist while in liberal arts women students are more likely to persist. In all other colleges, persistence is not significantly correlated with gender.

A possible explanation for the lack of gender dependence in other colleges may be other support structures dedicated to persistence and identity (e.g. "Women in Science," "Women in Computing," etc.) to support women. Students, faculty, and staff alike are encouraged to participate in frequent events. In the institute studied, such groups are lacking or less active for other demographics. This is also consistent with our finding that the AALANA/non-AALANA input has an effect on persistence in the colleges of engineering, computing, applied science, non-clinical health science, and liberal arts, where AALANA students persist at significantly lower rates than their non-AALANA peers.

Three of the four colleges that show DHH students persisting at lower rates than hearing students are STEM colleges. Across the U.S., state standards for interpreters are such that being able to translate a technical vocabulary is not a requirement. This leaves 60% of interpreters unequipped to handle the technical vocabulary that is often seen in STEM fields [19]. Though DHH students at this institute have unparalleled access to interpretation services, the overall reduced ability to translate technical content may contribute to the unequal switching of DHH students in these colleges.

Turning now to the environment-outcome connection, we find that, on average, students who switch out of non-STEM colleges remain in non-STEM majors at higher rates than students who switch out of STEM colleges remain in STEM majors. The individual probabilities of students switching out of certain colleges may suggest trends in which colleges are the most attractive to major-switching students who ultimately maintain their intended STEM/non-STEM field. For instance, we find certain origin-target college pairs to be more

Target \ Origin	Engineering$^\diamond$	Computing$^\diamond$	App. Sci$^\diamond$	Science$^\diamond$	N.C. Health Sci.$^\diamond$	Non-STEM
Engineering$^\diamond$	X	0.21	0.32	0.16	0.04	0.06
Computing$^\diamond$	0.28	X	0.38	0.16	0.11	0.19
App. Sci$^\diamond$	**0.45**	0.22	X	0.15	0.11	0.36
Science$^\diamond$	0.16	0.30	0.14	X	**0.57**	0.21
Non-clin. Health Sci.$^\diamond$	0.04	0.05	0.03	**0.40**	X	0.17
Non-STEM	0.06	0.22	0.13	0.13	0.19	X

TABLE III. Distribution of degree-earners who switch out of the origin college and into the target college. Percentages are normalized to the total number of students who leave each respective college. Values in **boldface** font exceed twice that which would be expected from random switching. Colleges marked with a diamond ($^\diamond$) are STEM colleges; non-STEM values reported are averages of the four non-STEM colleges.

than twice as likely as random switching. These include the directional engineering→applied science pair and the bidirectional science ↔ non-clinical health science pairs.

Majors within the engineering college and applied science college have nearly identical titles, though the majors in applied science include the qualifier "technology." The students who wish to have a more applied, and therefore less theoretical, education in an engineering field may migrate toward the applied science college. In fact, we find that students who switch from engineering to applied science often maintain the major concept (e.g., mechanical engineering) but declare in applied science (e.g., mechanical engineering technology). Several faculty in the college of applied science have earned some level of engineering degree and have expertise in engineering technology specifically. This means that the applied science college is a welcome environment for those looking to specialize in a technical field related to engineering.

The college of science and non-clinical health sciences are linked at the major level. Anecdotal evidence supports the notion that students who enter into non-clinical health science from "bio-X" majors do so based on a false notion that a degree and recommendation letter from a health science college is more attractive to medical schools.

VI. CONCLUSIONS AND FUTURE WORK

In both STEM and non-STEM colleges, demographics within a college have statistically significant effects on persistence. AALANA status and hearing status each show correlation with persistence in three of five STEM colleges (engineering, computing, and applied science); hearing status is significant for the colleges engineering, applied science, and non-clinical health science. Gender shows a strong effect on persistence in only two cases – one STEM college (computing) and one non-STEM college (liberal arts); men students persist at higher rates in computing than women students do whereas women students persist at higher rates in liberal arts than men students do. In many colleges, students who graduated in or before 2010 were more likely to maintain their original college than students who graduated following 2010. When considering the 4 non-STEM environments in combination with the 4 external factors, the non-STEM environments in general show fewer relationships with persistence (6 of 16) than STEM environments (10 of 20). We note that this may correlate with the availability of inclusionary groups specific to each college, rather than similar, national groups.

First-declared college affects both persistence as well as the ultimate degree-granting college. We find strong connections between several colleges, like the strong link between college of science's "bio-X" majors with non-clinical health science and the directional tie between the engineering college and applied science college. These college pairs teach closely related content, perhaps offering more welcoming environments for those who seek a more experimental career path than the one originally set upon.

Results from this work should inform efforts that encourage retention at scales below the institute, i.e. retention within a college, department or program. Future work can include students that do not graduate to examine whether the impact on students that leave an institute altogether react differently to the environmental variables. Additional work should also examine different institutional context, i.e. non-technical institutions, small liberal arts colleges and regional public universities that educate a high percentage of historically underrepresented populations.

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