Academic Outcomes of International Students in Chemical, Civil, Electrical, Industrial, and Mechanical Engineering in the USA

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***Abstract*—This research full paper explores the academic outcomes of undergraduate engineering students who leave their native countries and pursue their education in the USA. These "international students" are defined as students who were not citizens or permanent residents of the USA who enrolled in engineering programs in the USA. In this paper, we quantitatively analyze metrics for international and domestic students pursuing undergraduate degrees in one of the five most popular engineering disciplines in the USA: chemical, civil, electrical, industrial/systems, and mechanical using the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD). MIDFIELD includes institutional records from over 1.7 million undergraduate, degree-seeking students in 21 programs at nineteen universities in the USA with over 85,000 men and 21,000 women enrolled in one of the most popular five engineering disciplines in the USA. Metrics used include representation at the start of university studies, initial engineering major choice, six-year graduation rate, and stickiness (the number of students graduating in a major divided by the number of students who ever enrolled in that major). Results are disaggregated by origin (domestic or international), sex (female and male), and major (chemical, civil, electrical, industrial/systems, and mechanical). Results show that there are more men than women in these disciplines and this is more pronounced for international students. In these disciplines, international students graduate at higher rates and have higher stickiness than domestic students. International females have the highest graduation rates. Industrial/Systems Engineering has the highest graduation rates and stickiness for all populations. Insights from this work can inform student services personnel and others committed to international student success.**

Keywords*—undergraduate; international students; longitudinal; multi-institution; stickiness; graduation rate

I. Introduction and Background

The number of international students studying in the USA has increased steadily from the early 1960s until the 2017-18 academic year reaching nearly 1.1 million students and comprising approximately 5.5% of all students in US higher education. Over half of all international students come from China and India and just under 40% of them are undergraduates [1]. Engineering is the most popular field of study for international students; approximately one-fifth are studying in an engineering field [2]. In 2013, public institutions enrolled 64% of all international students in the USA. Because international students must demonstrate an ability to finance their education in full, their tuition is welcomed by states that have reduced their higher education spending [3]. Given their responsibility for tuition (which may come from personal/family, employment, or government sources [1]), affordability, along with the expected quality of education, is one of the top considerations for students choosing to study in the USA [4].

Several studies have explored factors leading to international student persistence from first to second year [5, 6], and first to third year [7] using data from national or multi-institutional datasets. The students' Grade Point Average (GPA) was found to have a significant positive effect for first to second and first to third year persistence [6, 7], while credit hours attempted positively influenced only first to second year persistence [5, 6]. There is mixed data on the importance of English language skills to persistence. Mamiseishvili [7] found that a need to enroll in remedial English classes was negatively related to persistence while Kwai [6] found no relationship between Test of English as a Foreign Language (TOEFL) scores and persistence. Wait and Gressel [8] found a positive relationship between TOEFL scores and GPA, although the relationship was weaker for engineering students.

There are several studies that have explored international student experiences during their first year studying engineering. Barnes and Loui compared the challenges faced by first-year domestic and international in adjusting to college [9]. Jimenez-Useche, Hoffmann, and Ohland compared the academic performance of domestic and international students in a required first-year engineering class [10]. Jimenez-Useche, Ohland, and Hoffmann also investigated the dynamics of first-year engineering teams that included domestic and international students [11]. Beigpourian, Ohland, and Ferguson studied psychological safety as it related to the percentage of international students on first-year engineering teams [12].

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In a single-institution study, Fass-Holmes showed that international students were academically successful in terms of graduation rate and time to degree completion [13]. However, few multi-institutional studies have been undertaken to investigate international students' persistence beyond the second year or outcomes such as graduation rate. Such studies focused on domestic students have demonstrated usefulness in examining outcomes for engineering students disaggregated by race and sex (e.g., [14]) and have also provided useful insights into students' experiences and how to support them (see, for example, [15]). In this work, we quantitatively explore the representation of international undergraduate students in the five most popular engineering disciplines in the USA at enrollment and examine the outcomes of six-year graduation rate and stickiness [16] as compared to domestic U.S. students. Given our large dataset, we disaggregate by sex to note how outcomes differ.

II. Methods

A. Dataset and Population

This study uses the Multiple-Institution Database for Engineering Longitudinal Development (MIDFIELD) [17, 18], which has been shown to be representative of US engineering programs [19]. MIDFIELD (release 2020.03.16.v9) includes institutional records from all undergraduate, degree-seeking students at nineteen institutions in the USA with data for 1987 through 2018. The MIDFIELD population includes 1,722,094 students, of which 290,492 students ever enrolled in engineering.

In this work, we define "domestic students" as students who are citizens or permanent residents of the USA and who enroll in engineering programs in the USA. All other students are considered "international students." For this study, we focus on the students who started or ever enrolled in the majors of interest using Classification of Instructional Programs (CIP) codes developed by the National Center for Education Statistics (NCES) of the United States Department of Education. This work uses the 2010 revision of these codes. Our study includes codes with the first four digits of 1407 (Chemical Engineering), 1408 (Civil Engineering), 1410 (Electrical Engineering), 1435 (Mechanical Engineering), 1427, 1435, 1436, and 1437 (Industrial/Systems Engineering) [20]. The remaining two digits of the six-digit codes are used to recognize sub-specialties and are not important to this work.

Table I shows the population of students ever enrolled in these five majors by sex and origin (domestic or international). Given our large dataset, we can disaggregate by sex to separately consider students who identify as female and male. We omit a small number of students for whom origin or sex are unknown. Only those with sufficient data to evaluate six-year outcomes [21] are included in Table I. For all four combinations of sex and origin, the average starting age is 20 years old.

B. Metrics

In this study, we use metrics that represent students' initial engineering major choices, graduation rates, and longitudinal stickiness. All metrics account for the criteria for data sufficiency and, for graduates, timely completion [21]. Representation at the start of university studies considers the number of students when they first enroll at an institution, describing, for example, the students who begin their studies intending to graduate in chemical engineering. To avoid miscounting students, First-Year Engineering (FYE) programs require special care.

Treatment of FYE programs. At some US institutions, engineering students are required to complete a non-specialized First-Year Engineering (FYE) program as a prerequisite for declaring a specific engineering major. When computing a metric such as graduation rate that requires a count of *starters* in a major, we predict the degree-granting engineering majors that FYE students would have declared had they not been required to enroll in FYE. These *FYE proxies* are CIP codes that substitute for FYE programs when a metric requires a degree-granting starting major.

Our treatment yields two types of proxy. The first type comprises students completing FYE and enrolling in an engineering major—the known post-FYE engineering major is the proxy. The second type comprises students not enrolling post-FYE in an engineering major. For these students, the proxy is treated as missing data and is imputed using the Multivariate Imputation by Chained Equations (MICE) algorithm implemented in the R *mice* package [22].

The MICE predictor variables are institution, starting year, sex, and origin (international or domestic). Imputation was conducted in five iterations, each with five multiple imputations, acting on all FYE students in the MIDFIELD database. After imputation, retaining the starters in the five majors of this study (defined by the CIP codes described earlier) yields 32,459 proxies of the first type (known post-FYE engineering major) and 126 proxies of the second type (imputed missing data). By making these predictions, we account for the experience of all FYE students, avoid undercounting disciplinary starting cohorts, thereby avoiding overestimates of disciplinary graduation rates.

Initial Engineering Major Choice is the percentage of a population (e.g., domestic females starting in engineering) who choose a specific engineering discipline (e.g., Chemical or Electrical Engineering). This population includes FYE proxies.

Graduation rate is the percentage of students starting in a major who graduate in that major within six years. Starters include the FYE proxies.

Longitudinal stickiness is the ratio of the number of students graduating in a program to the number of students ever enrolled in that program. Stickiness measures the extent to which a program succeeds in graduating the students it admits, without regard to how or when a student is admitted to a program—the metric includes students who begin college part-time, enroll mid-year, switch majors, or transfer, in addition to first time-in-college students [16].

The stickiness metric uses students who were ever enrolled in a specific discipline because only then has a program made a commitment to the success of a student. Because stickiness does not depend on the starting program, FYE proxies are unnecessary. Furthermore, a student who changes majors is counted in each of the five majors in which they were ever enrolled. Thus, the number of ever-enrolled students in Table I (123,863 unique students, some of whom were "ever" in more than one of the five majors studied) differs from the number of starters in Table II (96,395 unique students).

TABLE I. STUDENTS EVER ENROLLED IN THE FIVE MOST COMMON ENGINEERING MAJORS IN THE USA

Group	Ever Chemical	Ever Civil	Ever Electrical	Ever Industrial/Systems	Ever Mechanical
Domestic Female	6382	5118	3970	4548	4554
Domestic Male	11126	19751	25164	8707	32796
International Female	424	246	403	317	217
International Male	894	1075	2919	1258	2083
TOTAL	**18826**	**26190**	**32456**	**14830**	**39650**

C. Limitations

There are several limitations to this work. Although international students share the experience of studying in the USA, the category of "international" represents a large aggregation of students from around the world who are diverse in terms of race, ethnicity, socioeconomic status, citizenship, and native language. We are not able to disaggregate by country of origin which certainly impacts students' cultural adjustment. Some of these students completed their secondary education in English-speaking programs but we are not able to consider this. Some governments finance their students' study in the USA while other students are supported by themselves or their families [3], whose financial resources must be sufficient to support all of their education and provide proof of this at enrollment. Tuition at public colleges in the USA is considerably higher for international students. Experiences also vary by institution. Our consideration of sex is limited by institutional data collection practices and U.S. Department of Education reporting standards during the study period [23]. Students had the option of choosing male or female at all institutions. Some institutions reported other options, but those are excluded from our analyses to protect small, potentially vulnerable populations. All of the data reported on here is from before the COVID-19 worldwide pandemic, which has had a profound impact on travel and the ability of international students to study in the USA, although many continue to study at US universities remotely.

III. RESULTS

A. Representation at start of university studies

In MIDFIELD, as seen in Table II, there are far more domestic students than international students at the beginning of university studies. As reported in studies throughout the USA, there are more male students in engineering than female [15, 24, 25]. This is even more pronounced for international students in Industrial/Systems where 4 times more international males than females start (940 vs. 233) compared to 1.8 times for domestic males and females (4569 vs. 2515). In Mechanical Engineering, 10.9 times more international males than females start as compared to 7.7 times for domestic males and females.

At the start of university studies, international students in all five disciplines have a lower percentage of women compared to domestic students which varies by discipline and is most pronounced in Industrial/Systems, where 20% of international students are women compared to 36% of the domestic students. The others are more similar in the percentage of women, at 30% vs. 36% for Chemical, 18% vs. 20% for Civil, 8% vs 11% in Mechanical, and 12% vs. 13% for Electrical. The similarity of the gender distribution in the international and domestic students is striking, given the different levels of participation of women in countries around the world, and may have more to do with U.S. admissions practices than the application behaviors of students outside the USA.

B. Intital Engineering Major Choice

Fig. 1 shows the initial engineering major chosen by students in this study. This data shows that being an international student strongly influenced the choice of major for the students at institutions in this study. International men and women chose Industrial/Systems and Electrical at higher rates than their domestic counterparts. Domestic students chose Chemical, Civil, and Mechanical Engineering at higher rates than international students. Female students, both domestic and international, chose Industrial/Systems, Chemical, and Civil Engineering at higher rates than their male counterparts. Female students chose Electrical and Mechanical Engineering at lower rates than their male peers. For all majors, the direction of the difference (lead or lag) between international and domestic students is in the same direction for both men and women of each group. International men choose Civil and Chemical Engineering at the lowest rates; International women chose Civil and Mechanical Engineering at the lowest rates. Domestic men, who are the largest population, chose Mechanical and Electrical Engineering at the highest rates.

TABLE II. STARTERS IN THESE DISCIPLINES

Group	Chemical	Civil	Electrical	Industrial/Systems	Mechanical	**TOTAL**
Domestic Female	5197	3610	2993	2515	3175	**17490**
Domestic Male	9049	14081	19288	4569	24532	**71519**
International Female	307	166	303	233	145	**1154**
International Male	710	762	2243	940	1577	**6232**
TOTAL	**15263**	**18619**	**24827**	**8257**	**29429**	**96395**

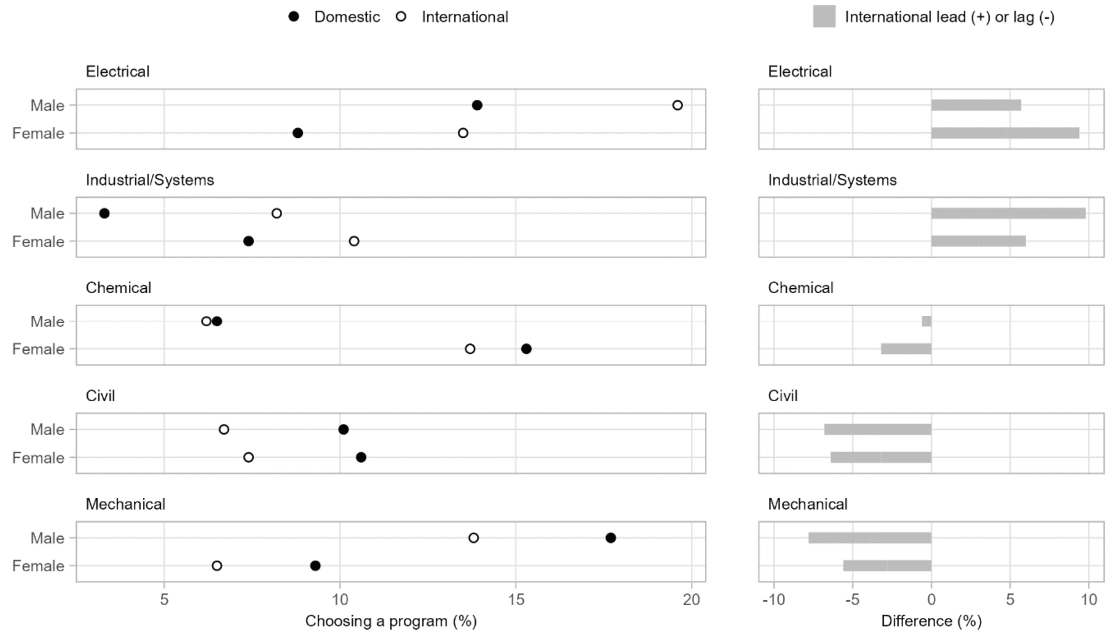

Fig. 1. Initial enginering major choice of international and domestic (USA) students disaggregated by sex and major. The "Difference" chart illustrates the percentage by which International students lead (+) or lag (–) Domestic students in their choice of program. Based on data from Table II.

C. *Graduation Rate*

Fig. 2 shows the six-year graduation rate for students in these five engineering majors by sex and origin. The dashed line represents the overall graduation rate for that major. Given the large population of domestic males for each major, this average is dominated by their rates. For all majors studied, international female and male students graduate at higher rates than domestic students. International female students graduate at the highest rates for each major with international males second.

Students graduate in Industrial/Systems Engineering at higher rates than the other disciplines. The lowest graduation rate in Industrial/Systems engineering is 60.5% for domestic males, which is higher than the graduation rates for all but one group in the other four majors. Female students graduate at higher rates than their male peers for all populations and majors except for Chemical Engineering (domestic) where the rate for males (48.6%) is slightly higher than for females (47.2%).

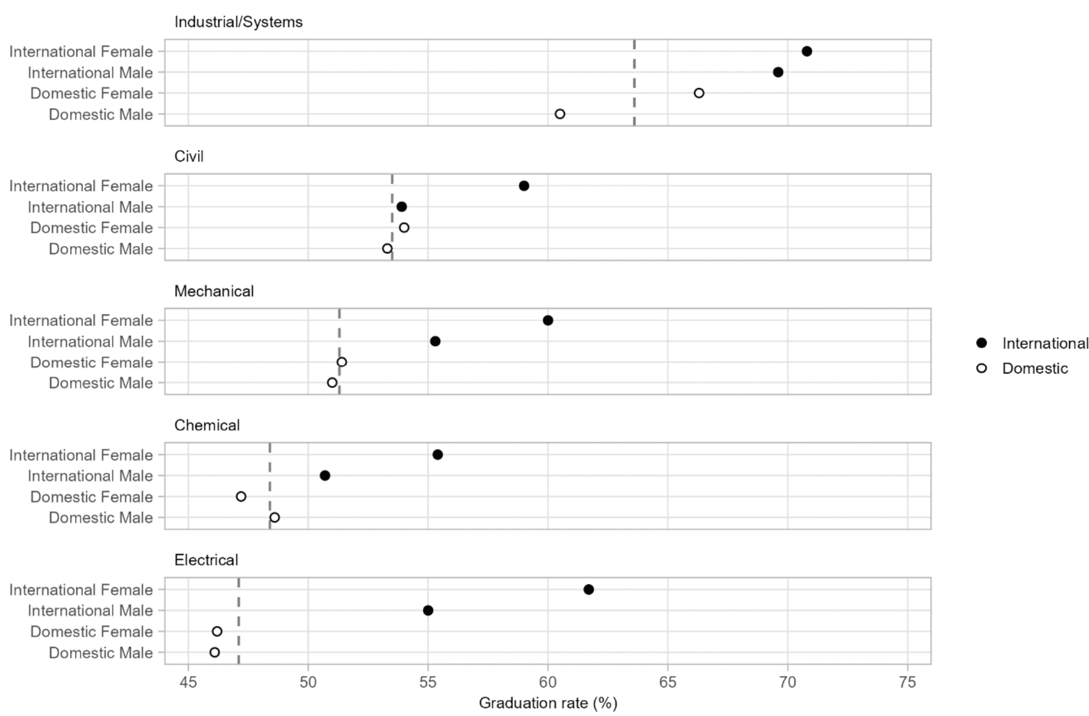

Fig. 2. Six-year graduation rate of international and domestic (USA) students disaggregated by sex and major. Based on data from Table II.

D. Longitudinal Stickiness

The assumption that students who select a major intend to graduate in that major leads to a corollary assumption: when a student is allowed to major in a degree program (via any pathway), a commitment has been made by the institution and/or program that the student will be supported to graduate in that major. Thus, stickiness is not a measure of attractiveness to students, but it is fundamentally a measure of the degree to which a program (or group of programs, or university) lives up to that commitment.

Several stories arise from Fig. 3 which shows the stickiness for international and domestic male and female students. Once international students declare one of these five majors, they are more likely than domestic students to graduate in that major. International women have the highest stickiness percentage in all five majors and international men have the next highest. Female domestic students have higher stickiness in all majors except Chemical. Stickiness is higher in Industrial/Systems Engineering than all other majors studied.

Because stickiness is based on whether a student ever enrolled in a major, students are counted more than once if they migrate among these majors. Students contribute to the denominator of the stickiness ratio for every program in which they enroll; they contribute to the numerator of the ratio only for the program from which they graduate. That said, nearly all students in the study were only ever enrolled in one of these five majors (87% of domestic females, 92% of international males, 94% of international females, and 88% of domestic males).

IV. Discussion

We do not have evidence to support a reason for the finding that international men and women choose Civil Engineering at the lowest rates. More research is needed in this area. Perhaps the localized nature of some fields of civil engineering—that it depends on regional building codes, practices, and licensure—plays a role, so that students choose to stay in their home country rather than travel to the USA.

The higher rate at which domestic men chose Mechanical and Electrical Engineering is consistent with the literature. These are the largest majors in terms of enrollment and have the highest percentages of men among this group of majors [26]. When all engineering disciplines are aggregated, Mechanical and Electrical dominate the discussion. Among domestic students, research has shown that White students prefer Mechanical Engineering to Electrical Engineering while Asian and Black students prefer Electrical to Mechanical and Hispanic students choose Electrical and Mechanical at equal rates [27]. The high graduation rates for students in Industrial Engineering are consistent with prior work [28] suggest that this discipline is doing some things well, indeed, it has been dubbed "Inviteful Engineering" [29] for its welcoming and supportive environment.

As shown in the findings, for the five engineering majors studied here, international female and male students graduate at higher rates than domestic students. This is consistent with prior work that considered engineering overall as well as work that focused on Electrical Engineering majors [30, 31]. International female students graduate at the highest rates for each major with international males second. Previous studies

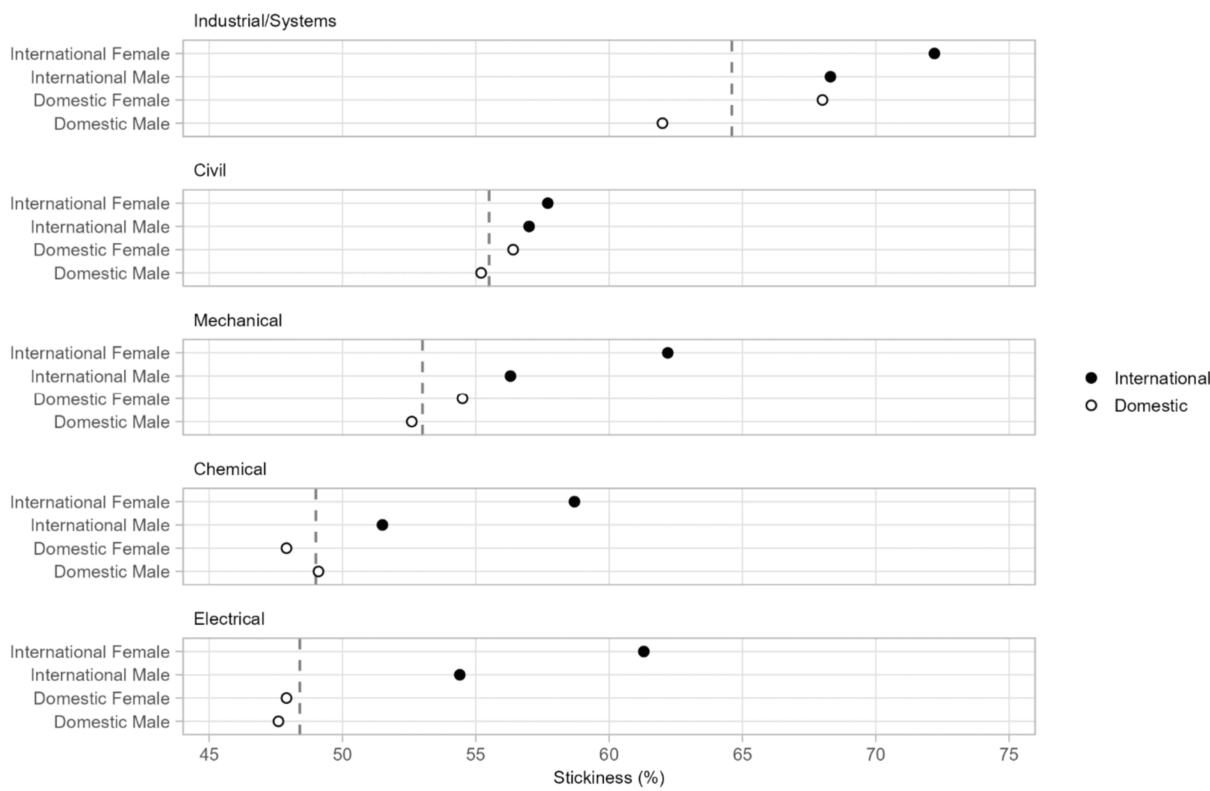

Fig. 3. Longitudinal stickiness of international and domestic (US) students disaggregated by sex and major. The vertical dashed line is the stickiness of the program as a whole. Based on data from Table I.

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have shown that domestic females graduate in six years at the same or better rates than their male peers of the same race/ethnicity in engineering overall [15, 32, 33] and in these five majors [15]. Previous work for all engineering showed that international females graduated similar rates to international males [30].

It is difficult to hypothesize the results that international students have higher graduation rates and stickiness. The high academic qualifications of international students and their high level of financial support would support this finding, yet the transition to US language and cultural practices and the likelihood that international students will encounter xenophobia and stereotyping might suggest the opposite result.

We remind readers of the limitation that these groupings of international and domestic are large aggregations with students from many different experiences. More research is needed to explore students' experiences and motivations.

V. Conclusions

This study of international students in the top five most popular undergraduate majors in the USA (i.e., Civil, Chemical, Electrical, Industrial, and Mechanical Engineering) disaggregated by sex and major provides insights into the representation and outcomes for these students. Graduation rates are higher in all five majors for international females and males than their domestic peers. Graduation rates in Industrial and Systems Engineering are higher than for every other major suggesting cultural differences among these majors that would be valuable to study. This study reveals that the international student population in these five majors has better academic outcomes than domestic students and higher stickiness in their chosen major than domestic students, revealing their resilience to the challenges of adapting to the language and culture of the USA. Insights from this work can inform student services personnel and others committed to international student success.

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