

A MULTI-INSTITUTION STUDY OF STUDENT DEMOGRAPHICS AND OUTCOMES IN CHEMICAL ENGINEERING

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Studying the demographics and outcomes of Chemical Engineering (ChE) students provides valuable insight to the profession. Unlike many studies that aggregate all engineering majors,^[1-4] this work focuses on ChE. Chemical Engineering students have been shown to be different from other engineering students in terms of higher academic achievement on several academic performance criteria including high school grade point average (GPA), SAT math and verbal scores, time-to-graduation, and cumulative GPA.^[5] In a more recent study, Godwin and Potvin compared ChE students to other engineering students in terms of their career interests and attitudes.^[6] Using a sample of primarily first-year students, they found that ChE students were more likely to have taken higher-level chemistry in high school, had stronger desire to apply math and science in their careers, had a stronger interest in science and understanding the world, and had higher science identity. They did not find the differences in terms of academic achievement reported earlier and suggest some reasons due to differences in methodology, population, and time.

Around the world, ChE is known for having a relatively high fraction of women among engineering disciplines,^[5,7-10] but less work has been done to describe its racial and ethnic diversity. At a national level in the United States, the American Institute of Chemical Engineers (AIChE) recognizes the importance of promoting women and minorities in the profession through its Women's Initiatives Committee (WIC) and Minority Affairs Committee (MAC)^[11] and its inclusion of "uphold and advance the profession's standards, ethics, and diversity" in its mission statement.^[12] Since race/ethnicity and gender do affect experience, it is important to consider these factors. Most datasets are too small to permit disaggregation by both race/ethnicity and gender, let alone engineering discipline. However, the dataset

used in this research permits disaggregation by all three factors. Thus, this work uses a critical race theory framework^[13] and considers the intersectionality of race/ethnicity and gender.^[14]

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For example, the pathways of Asian women and black men can be considered rather than the pathways of “women” or “underrepresented minorities.” In this paper, we highlight literature focused on ChE and then use a large dataset to conduct a multi-institution study of the demographics and outcomes for students in ChE disaggregated by race/ethnicity and gender. We also use a recently formulated “stickiness” metric^[15]—named from the concept of *sticking with* a major—to compare all students regardless of their matriculation pathway [first-time-in-college (FTIC) or transfer students].

Our work provides an unprecedented look at the demographics of ChE by race/ethnicity and gender. To the extent that the findings from the institutions studied here are representative of other institutions, those institutions can learn from our findings and can explore how their institutions address these common challenges. To the extent that institutional findings differ from those presented here, institutions may either be able to share promising practices with the larger community or identify opportunities for improvement.

BACKGROUND

In the aggregate, there is no gender gap in engineering persistence as shown in many studies.^[1,16-22] In a large multi-institution study that aggregated engineering majors, no gender gap in persistence or graduation was found for all races/ethnicities.^[3,23] Lord, *et al.*^[7] showed that there were gender differences in major selection within engineering. In a mixed-methods, multi-institutional study of the largest and most common engineering disciplines, Brawner, *et al.*^[24] found that ChE had the highest representation of women at matriculation (39%) and at the third semester (38%) of any engineering major in the study (some disciplines, such as biomedical engineering, have been shown to have higher representations but are not as common and were not included). In a single institution study with 2,474 men and 613 women majoring in engineering, Stine^[25] also found that 10% of those men and 23% of those women chose ChE. This is the highest percentage for women of any engineering major in that study. Six-year graduation rates in the major were high compared with other engineering majors: 48% for men and 49% for women for ChE while the aggregated overall graduation rate in major was 43% for men and 42% for women. Felder, *et al.*^[26] conducted a detailed study of ChE students’ experiences, finding that men and women in an experimental ChE course sequence had similar four-year retention rates. Men were more likely to drop out and lag in the curriculum. Women were more likely to switch to another major in good academic standing.

In one of the few studies to examine gender segregation critically across engineering majors, Litzler^[8] combined data from the Engineering Workforce Commission (EWC) and the Project to Assess Climate in Engineering (PACE) survey. The EWC data contains information from all U.S. schools of engineering, while the PACE data includes 21 large, public, research-intensive universities. For both the EWC and PACE

data, ChE had higher representation of women than engineering as a whole. Only bioengineering and environmental engineering had higher representation, with industrial engineering and materials engineering equal. Litzler’s data show “clearly that there is a significant amount of variation at schools across the country in the proportion of women in chemical engineering.”^[8, p.97] She found that individual-level characteristics were more important than institutional variation in women’s major selection overall and particularly for ChE.

The extensive dataset used in this work allows for disaggregation by race/ethnicity, gender, discipline, and matriculation pathway to an extent never before attempted. Large national datasets such as IPEDS^[27] and that of the American Society for Engineering Education (ASEE)^[28] do not allow for this level of simultaneous disaggregation. Thus, the present study allows ChE faculty and administrators to learn about who enrolls and who succeeds in ChE in ways not possible using any other data source.

METHODS

MIDFIELD database and its demographics

This study uses the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD),^[29] a dataset with 137,649 FTIC students matriculating in engineering and 39,354 transfer students articulating in engineering at 11 public, generally large U.S. institutions, nine of which are in the Southeast region of the United States. The demographics of the overall database are described in Reference 30. To define a ChE program, we use the Classification of Instructional Programs (CIP) code that is assigned by the institution to a degree program.^[27] Ten of the 11 MIDFIELD institutions offered ChE during the years studied. MIDFIELD includes four of the top 20 ChE degree-granting institutions in the United States by size. MIDFIELD is representative of the United States in terms of the representation of chemical among engineering disciplines and percentage of women in ChE. For the entire dataset, ChE graduates make up 9.8% of engineering bachelor degrees awarded at MIDFIELD institutions. The most recent national data available indicate that ChE comprised 8.4% of all engineering bachelor degrees awarded in the United States.^[29, 31] Among women who received engineering bachelor degrees, 16.9% were in ChE in MIDFIELD while 14.7% were in ChE for national data.

It should be noted that there are potential limitations of the dataset. In particular, the participating institutions are mostly in the Southeast, which has different demographics than many other parts of the United States. Further, the participating institutions are all public and generally high-enrollment. While large public universities produce a majority of engineering graduates each year, the MIDFIELD data would not be expected to represent small, private engineering programs well.

The population studied in this work

Of the total MIDFIELD population, this work focuses on the 11,899 FTIC students and 2,370 transfer students who have a race/ethnic identity of Asian, black, Hispanic, or white; declared ChE as a major; and have sufficient data to calculate six-year graduation rates during the period from 1987-2010. We study students in multiple pathways: FTIC who matriculate directly into ChE or who choose ChE after completing a first-year engineering (FYE) program (where direct matriculation into specific engineering majors is not possible) (9,611 students); FTIC students who matriculate in other majors and switch into ChE (2,288); and transfer students who make their way into ChE (2,370). The group studied is representative of students in MIDFIELD in terms of race/ethnicity and is representative of students in ChE programs in the United States in terms of race/ethnicity—except for Hispanics, who are underrepresented (2.6% to 10.1%). The ChE group studied has a higher percentage of women when compared to the MIDFIELD engineering population (38% to 20%).^[29,31]

ChE programs at MIDFIELD institutions awarded between 14 and 106 B.S. degrees in 2005, with a median program size of 50 graduates per year.^[31] This is consistent with the fact that MIDFIELD partners are larger and have a larger fraction of engineering enrollment than is typical.^[4]

By comparison, the median number of graduates of ChE programs in 2005 at a U.S. institution (counting only institutions offering ChE) was 22.^[31]

Metrics used in this work

Several metrics are used in this analysis: the race/ethnicity-gender of those who start in these majors; trajectories of students; six-year graduation rates; and “major stickiness.” Of these metrics, stickiness requires elaboration. Major stickiness is the number of students who graduate in a major divided by the number of students who ever declared that major. Stickiness contains richer information than other persistence metrics; one of its critical benefits is its ability to pool data for students who enter engineering at different curricular points, including a large number who enter through first-year engineering programs.^[15] Students in FYE programs who are not permitted to enroll in a specific engineering major at matriculation are counted at the time they commit to a major in an administrative sense.

To facilitate the comparison of the pathways of ChE students at schools with FYE

programs and schools where students matriculate directly to specific engineering majors, the Year 0 ChE enrollment at FYE schools is imputed by allocating the total FYE matriculated population to specific majors at enrollment in the same proportion as students chose each major after FYE. This assumes that the retention through the transition from FYE programs is the same for all engineering majors.^[32] Throughout this paper, the term “starters” refers to the total of FTIC students who matriculated directly in a major and those imputed to start in that major. “Transfers” refers to students who were designated as transfer students by the participating institutions. Transfer students are assigned as starting in a particular curricular semester, where for every 15 credits they transfer, their starting semester is increased by one.

In this paper, graduation is defined as having graduated by the sixth year from matriculation.^[27] We include the Year 4 outcome in addition to the Year 6 outcome because differences in graduation rate among students enrolled beyond the expected time-to-graduation have been observed when data are disaggregated by race/ethnicity and gender.^[3] Because MIDFIELD is whole population data, no sampling is involved. Consequently, differences are not compared in terms of statistical significance. Any differences between populations are real, although some may not be meaningful.

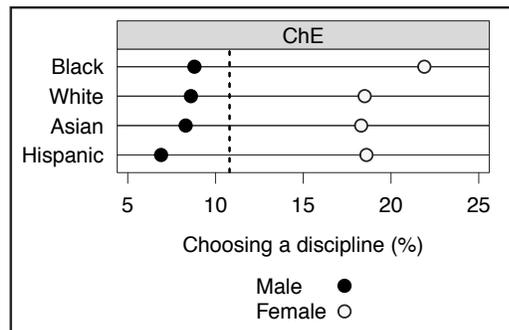


Figure 1. Starters choosing ChE.

RESULTS AND ANALYSIS

Matriculants in ChE

1) Who starts in ChE?

Focusing on ChE starters, Table 1 shows the number of engineering (ENGR) starters in this dataset and the number choosing ChE disaggregated by race/ethnicity and gender. The percentages of engineering starters choosing ChE are shown in Figure 1. The vertical

Race/Ethnicity-Gender	Starters in ENGR	Starters in ChE	% ChE
White Male	58079	5011	9
Black Male	5943	524	9
Asian Male	4081	337	8
Hispanic Male	1922	132	7
White Female	13675	2530	18
Black Female	3523	773	22
Asian Female	1119	205	18
Hispanic Female	531	99	19
All Male	70025	6004	9
All Female	18848	3607	19
All Students	88873	9611	11

reference line shows the 11% percent of all students choosing ChE. Data markers to the right of the aggregate values indicate populations choosing ChE at rates higher than average.

Women of all races/ethnicities are particularly attracted to ChE. Women of each racial group in engineering are dramatically more likely than men to start in ChE. For all races/ethnicities aggregated, women engineering starters are more than twice as likely to choose ChE as men (19% vs. 9%). This is consistent with the data reported by Stine.^[25] The largest gender gap in enrollment is seen for black students, and black women have the highest percentage (22%). Note that the preference of black women for ChE results in more black women starting in ChE than black men despite black men outnumbering black women in engineering overall.

2) Six-year graduation: How do ChE starters do?

Six-year graduation rate data for starters in ChE and for starters in a family of engineering disciplines (aerospace, bio, chemical, civil, computer, electrical, industrial, and mechanical engineering) are tabulated in Table 2 and graphed in Figure 2. The vertical hash marks indicate a population average: the percentage of a race/ethnicity-gender group starting and graduating within six years in the same discipline aggregated across a family of disciplines.

Regardless of race/ethnicity and gender, ChE starters graduate in ChE at rates comparable to or above their population average. Asian women are the most successful with the highest graduation rate and largest difference from their population average for engineering overall. Asian and black students and white men in ChE are also noticeably above their population averages. Hispanic men graduate in

ChE at rates slightly better than in other specific engineering disciplines while white and Hispanic women in ChE are slightly below. Even so, Asian students, particularly women, are notably successful in ChE. Except for the Asian students, these graduation rates are lower than those reported by Stine for a single-institution study with all races aggregated.^[25]

Combining all engineering disciplines, research has shown that women of all races/ethnicities graduate at comparable or higher rates to men.^[3] This finding holds for ChE by itself. Asian, black, and Hispanic women graduate at higher rates than their male counterparts. White men and women have almost identical graduation rates with men slightly higher (40.9% vs. 39.8%).

Trajectory of ChE student enrollment

The graduation rates of starters ignore students who start in other majors or other institutions—who constitute a noticeable fraction of graduates. Specifically, transfer students and students starting in majors other than engineering (most commonly in an undecided pathway) make up 31% of ChE graduates (and fractions ranging from 27% to 66% for other engineering majors). Students who start in other engineering majors and graduate in ChE also add to that number. Focusing on completion statistics also ignores the path students take, such as when students enter and leave a major.

Figure 3 is a collection of time-series plots showing the number of students enrolled in ChE at matriculation (year 0), 4 years later, and 6 years later, disaggregated by race/ethnicity and gender. The vertical scale (numbers of students) is logarithmic in base 2. The horizontal scale (years from matriculation) is linear.

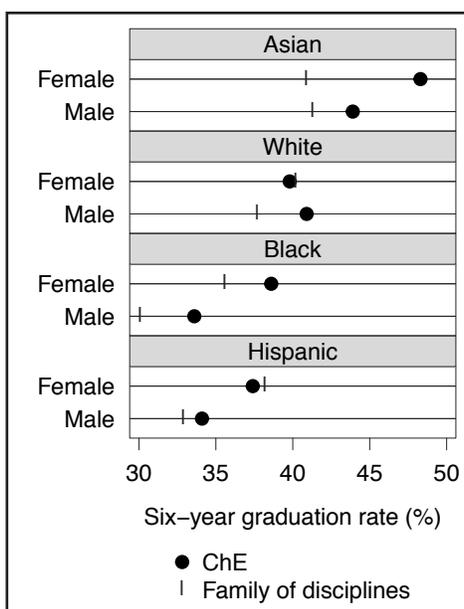


Figure 2. Starters graduating in six years.

Race Ethnicity-Gender	ChE			Family of disciplines		
	Starters	Six-yr grad	Rate(%)	Starters	Six-yr grad	Rate(%)
Asian Female	205	99	48	871	356	41
Black Female	773	298	39	2989	1063	36
Hispanic Female	99	37	37	422	161	38
White Female	2530	1007	40	10526	4235	40
Asian Male	337	148	44	3409	1407	41
Black Male	524	176	34	5187	1560	30
Hispanic Male	132	45	34	1546	508	33
White Male	5011	2051	41	47852	18048	38

While many starters leave, others take their place. Large losses are seen for all starters. The shallower slopes of the “all” curves show that students of each population are entering the major, compensating for starters who are leaving. In fact, in ChE, more Asian students graduate than start due primarily to the influx of students into the major.

Trajectories in ChE differ by race/ethnicity but not gender.

From matriculation until Year 4, starters’ trajectories have similar slopes for all racial/ethnic groups. Between Years 4 and 6, however, there are steeper negative slopes (indicating higher percentage losses) for black and Hispanic students compared with white and Asian students. As stated earlier, ChE gains Asian students from matriculation to graduation. The influx of Hispanic males results in more students at Year 4 than matriculation but those gains diminish by Year 6. Black students have the steepest slopes indicating the highest percentage losses. Cross-sectional studies, which calculate

graduation rates by dividing the number of students graduating by the number who were enrolled six years earlier, mask the striking losses of matriculants. For example, ChE graduates about as many Asian males as it enrolls initially, which would be calculated as a 100% retention rate if we simply compare graduates to starters. This hides the true behavior—that half of the starters are gone and have been replaced with other students: transfers and students from other majors. Interestingly, the trajectories for each racial/ethnic group are similar for female and male students, so trajectories in ChE do not appear to differ by gender to the extent that has been found for other engineering disciplines. Even comparing the trajectories of all female and all male Hispanic students, where the difference is noticeable, the difference is smaller than has been observed for other engineering disciplines.^[30,32]

Stickiness of students in ChE

The presentation of trajectories in the previous section is useful and disaggregates student pathways, but is also complex, requiring 16 trajectories with three data points each to describe the enrollment and graduation behavior of the various populations. Here, then, it is useful to employ another metric that can pool students coming from different pathways. As noted earlier, the major stickiness is the number of students who graduate in a major divided by the number of students who ever declared that major,^[15] regardless of the path by which students enter the major. These data are tabulated in Table 3 and graphed in Figure 4 (page 236) where the vertical reference line indicates the aggregate stickiness for all students in ChE.

Asian females have a surprisingly high stickiness in ChE, with Asian males, white students, and Hispanic females trailing by approximately 8% at the aggregate value. Women were found to have higher stickiness than their male counterparts for each race/ethnicity in EE and ME.^[32] This is true for Asian, black, and Hispanic women in ChE. White women, however, are slightly less likely to stick in ChE than their male counterparts (52% vs. 53%). Black students and Hispanic men

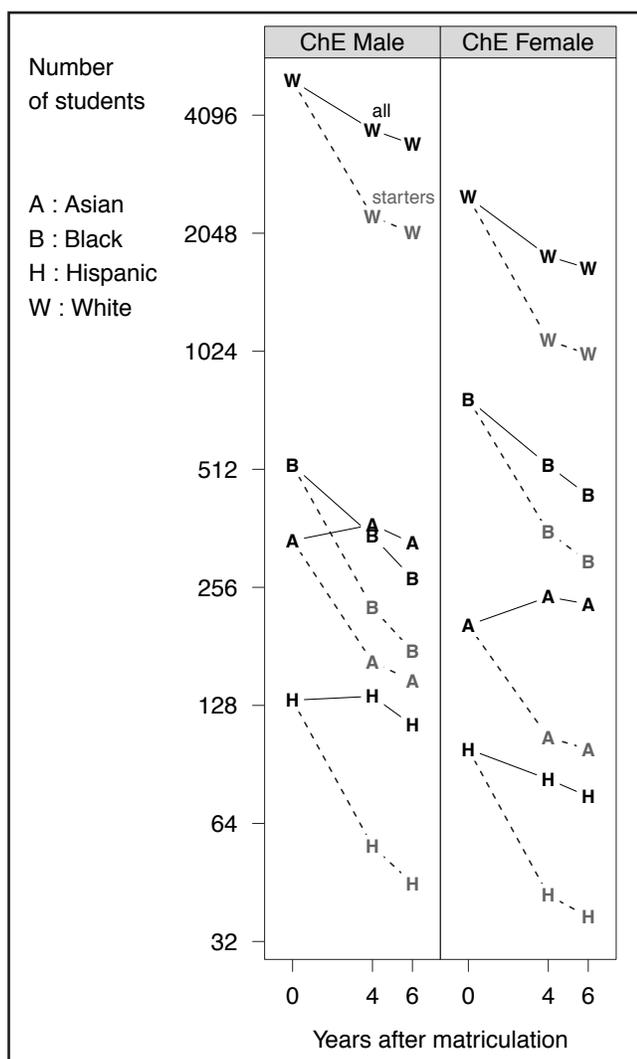


Figure 3. Trajectories of starters (dashed gray line) and all students (solid line) by race/ethnicity and gender.

Race/Ethnicity-Gender	Grad in ChE	Ever in ChE	Stickiness (%)
Asian Female	232	389	60
Black Female	439	1053	42
Hispanic Female	75	146	51
White Female	1666	3197	52
Asian Male	332	647	51
Black Male	270	702	38
Hispanic Male	114	246	46
White Male	3455	6495	53
All	6563	12845	51

TABLE 4
Stickiness of FTIC and Transfer Students in ChE

Race/Ethnicity-Gender	FTIC			Transfers		
	Grad in ChE	Ever in ChE	Stickiness (%)	Grad in ChE	Ever in ChE	Stickiness (%)
Asian Female	174	285	61	58	104	56
Black Female	360	888	41	79	165	48
Hispanic Female	48	108	44	27	38	71
White Female	1410	2712	52	256	485	53
Asian Male	233	467	50	99	180	55
Black Male	213	573	37	57	129	44
Hispanic Male	80	180	44	34	66	52
White Male	2770	5286	52	685	1209	57

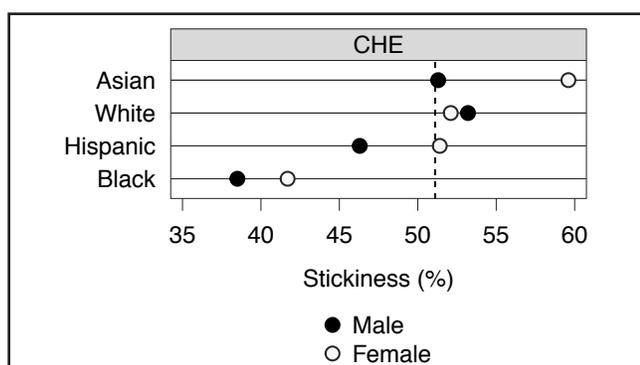


Figure 4. Stickiness in ChE.

have the lowest stickiness echoing the pattern seen in the trajectories of Figure 3 and graduation rates of Figure 2. These stickiness values clearly below the aggregate suggest unique struggles for these populations in ChE that merit further qualitative analysis. There might also be value in exploring the reasons why Asian females are so likely to stick with ChE.

Transfer students

Stickiness data for ChE transfers and FTIC students disaggregated by race/ethnicity and gender are tabulated in Table 4 and displayed in Figure 5.

The overall stickiness behavior for transfer students in ChE is similar to that of starters, with women having higher stickiness overall and black students and Hispanic males having lowest stickiness. White male and female starters have almost identical stickiness while white male transfers have slightly higher stickiness than white female transfers. Female transfer students of all race/ethnicities except

white are more likely to “stick” with ChE than their male counterparts. Hispanic female transfers are the most successful of all populations studied here (71.1%). This is in marked contrast to their stickiness as starters. Asian female transfers do only slightly better than Asian male transfers.

Consistent with earlier work,^[15] transfer students tend to be more sticky than FTIC students. This is likely related to their having already successfully passed some engineering prerequisites and thus being more strongly committed to the major before entering our database. Asian women in ChE are unique in that FTIC have higher stickiness than transfers. This unexpected behavior could be related to the very high stickiness of FTIC Asian women and suggests the need for qualitative work in this area.

DISCUSSION

These results are intended to inform faculty about the students in the ChE classroom and the relative success of different populations. Department heads can benefit from this information by learning about which populations are underrepresented in ChE as well as which may need more support to be successful. Deans who must balance the performance and needs of all engineering disciplines can benefit from learning about the particular challenges that each discipline faces in recruiting and graduation. For example, the attractiveness of ChE to women may inform recruiting efforts that attract more women to other engineering disciplines. ChE department heads can compare their demographics and outcomes to those described here as a detailed baseline.

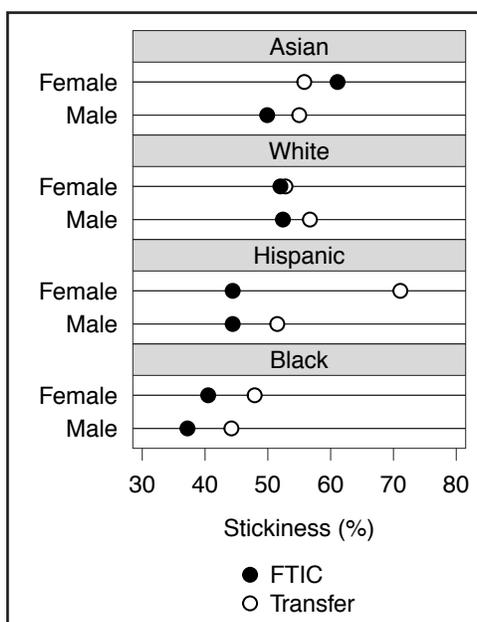


Figure 5. Stickiness of FTIC and transfer students in ChE.

The overall success of students in ChE might be linked to their reported better academic preparation than other engineering students (high school GPA, SAT math and verbal).^[5] The research presented here adds depth to the description of this success by showing the variation by race/ethnicity and gender.

The higher percentage of women in ChE compared to other engineering disciplines is supported by our work and consistent with earlier studies that showed that, with race/ethnicity aggregated, ChE attracts a higher fraction of women than other majors.^[5,7] We showed that this behavior begins at matriculation. This is in stark contrast to findings for electrical and mechanical engineering, which consistently attract women at much lower rates than their representation in engineering as a whole.^[32] This suggests that ChE is doing something right when it comes to recruiting women that other disciplines could learn from.

Godfrey asserts that, compared to other engineering disciplines, ChE has a less “macho” culture, which created “an environment in which women were treated as individuals, rather than generalized as a group.”^[10] She also suggests that women might be drawn to ChE because “a reliance on prior practical knowledge or tinkering experience did not seem as essential.” Previous qualitative work showed that motivations for women choosing ChE included flexibility and career opportunity.^[24] Findings by Godwin and Potvin may provide the best explanation of why ChE attracts a higher fraction of female students, although their research on student motivation of ChE students did not disaggregate by gender.^[6] They found that ChE students were more likely than other engineering students to want to address energy (60% vs. 47%), disease (39% vs. 18%), climate change (20% vs. 11%), and water supply (34% vs. 19%) in their future careers.^[6, p. 149] These opportunities are consistent with the messaging recommended by the National Academy of Engineering’s Changing the Conversation^[33] and subsequent Messaging for Engineering.^[34] Thus, some of the messages that ChE has been communicating (through recruiting materials, websites, etc.) fit well with messages shown to be attractive to women engineering students. As more is understood about the climate for women in ChE, educators might benefit from the work of Hoh, who developed an activity that highlights prominent women in ChE to break down stereotypes and raise awareness of women’s contributions to the field.^[35] Whereas these earlier findings are helpful in understanding why ChE attracts a higher fraction of women, more qualitative research is needed to explore the reasons why women persist in ChE at higher rates than men.

The particular success of Asian women in ChE is interesting. Our findings of high graduation rates for Asian men and women are consistent with literature showing that Asian students have the highest rates of matriculation and persistence in engineering and science of all racial/ethnic groups^[36-38] and that the interest in engineering and science careers starts as early as eighth grade.^[39] The model minority stereotype may

also play a role in Asian students choosing engineering and ChE.^[40] Because Asian-American students are assumed to be good at math and science, they may be encouraged to pursue careers such as engineering by their families, teachers, and guidance counselors. For Asian-American women, this may counteract some of the negative messages about engineering as a fit for women. Our findings of high graduation rates for Asian ChE students also resonates with work by Marra, Rodgers, Shen, and Bogue where Asian students were the only racial/ethnic group to see a slight increase in reported feelings of inclusion after a year of engineering study.^[41] None of this literature disaggregates by both race/ethnicity and gender to consider the unique experiences of Asian women. Such work would help in understanding our quantitative results.

While challenges exist for black students, this has been found for other disciplines as well.^[30,32] There is evidence that this is less a racial/ethnic effect and more a socioeconomic effect, noting that black students in MIDFIELD are more likely to come from low-socioeconomic-status high schools.^[42]

In ChE, Hispanic female transfers have the highest stickiness of all populations studied (71.1%). Hispanic women transfer students were also found to have high stickiness in EE (68%), ME (62.5%),^[32] and engineering overall.^[43] This suggests that the success of the transfer pathway for Hispanic females is not a disciplinary effect.

CONCLUSION

Using a large, multi-institutional dataset, we show that trajectories for ChE students differ by race/ethnicity. Chemical Engineering is different from other engineering disciplines in that trajectories do not differ by gender to the extent observed in engineering in the aggregate and in other specific disciplines. In this dataset, men outnumber women in ChE except among black students. While ChE starters graduate in ChE at rates comparable to or above their racial/ethnic population average for engineering, women choose and graduate in ChE at similar or higher rates than men of the same race/ethnicity. Typical of other engineering disciplines, external transfers and internal switchers replace starters who leave. Transfer students are generally more successful than starters. However, Asian women who start in ChE graduate at a higher rate than other populations and are more successful than Asian women transfers. These findings highlight the need to disaggregate by race/ethnicity and gender to expose intersectional effects.

ACKNOWLEDGMENT

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