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Factors Affecting Women's Persistence in Chemical Engineering*

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Chemical Engineering (ChE) is one of the engineering disciplines with the highest participation of women. This article describes the experiences of Black and White women in chemical engineering programs that stand out because they attract and retain women at higher rates than peer institutions. We use a mixed-methods approach, quantitatively describing the trajectories of Black and White students at three Selected and seven Other institutions using data from a large, multi-institution dataset and qualitatively describing the experiences of seven Black and nine White women through focus groups at those Selected institutions that were identified as "pockets of success" for women through the quantitative findings. We find that Black and White students have better outcomes at Selected institutions than at Other institutions; they are more likely to graduate within six years and more likely to remain in ChE. We find through focus groups that women are attracted to their institutions and departments due to institutional reputation and identify six reasons that these women stay in ChE at these institutions: Sisterhood, Real-World Experience, Real-World Examples, Faculty Caring, Sense of Accomplishment, and "I Got This Far." We conclude that institutional reputation is a factor in students choosing the institution but that the elements of reputation are different at the Selected institutions. Persistence in ChE appears to be most highly associated with relatedness. This can manifest through relatedness with other students, faculty who care, and the larger professional community through real-world experiences and examples.

Keywords: chemical engineering; graduation rates; persistence; student retention; stickiness; women

1. Introduction

Chemical engineering (ChE) is one of the engineering disciplines with the highest participation of women at approximately 35% compared with 20% in engineering as a whole as shown in various quantitative studies [1–5]. In this explanatory mixed-methods study, we seek to answer the question: *Why do women choose and remain in chemical engineering?* We focus on Black and White women who are successful in ChE at institutions that are successful for these women. We explore their experiences in ChE programs and why they stay. Our data is robust enough to allow us to consider race as well as gender using a critical race theory framework [6, 7]. Critical race theory acknowledges White privilege and its consequences and the role that institutions have in preserving power over time. While critical race theory tends to focus on the law as the mechanism of institutionalization, in our work, we consider the role that the culture and policies of an institution or discipline play in maintaining that privilege. Our earlier work has shown that some ways that success has been measured in engineering education are affected by a systematic majority measurement bias, which masks and maintains White privilege [8]. Our work also rests on and adds to our understanding of college impact models of student success, in particular the Input-Environment-Outcomes model of Astin [9]. Because we study the entire population of enrolled students at the institutions and years studied, our work places less emphasis on the input part of the model, but rather focuses on the influence of institutions and disciplines on the outcomes of choice, persistence, and attrition. While Astin's model has been criticized for its lack of consideration of the role of student decision-making in determining college outcomes, our use of the critical race theory framework keeps our focus on the institution and discipline and its role in granting and maintaining privilege, so the limitations of Astin's model are not a significant shortcoming in this work.

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2. Background

Much of the student success literature actually focuses on failure, likely because negative events have a greater impact and are more likely to be remembered [10]. Several important examples come to mind, including foundational titles such as Seymour and Hewitt's *Talking about Leaving* [11], and Tinto's *Leaving College: Rethinking the Causes and Cures of Student Attrition* [12]. Where pockets of success can be identified, they offer an opportunity to think differently about student success, informing the attainment of positive outcomes rather than the avoidance of negative ones. A pocket of success (POS) is defined in relative terms as an institution, program, or point in time for which outcomes are better than expected in comparison to other institutions in the aggregate, the same program at other institutions, or at other points in time. Outcomes of interest include access (attracting more students than expected in general or from a specific population) and persistence (having a higher than expected six-year graduation in the aggregate or for a specific population) [13]. Other work has shown industrial engineering to be a pocket of success for women [14, 15]. It attracts and retains women in the discipline at the highest rate of any of the larger engineering disciplines. Electrical, and particularly computer engineering, are much less successful [16, 17].

Tinto, whose work is classified alongside Astin's as a college impact model, identified "principles of effective retention" which include an "enduring commitment to student welfare" and an emphasis on the importance of social and intellectual community in the education of students [12, pp. 145–7]. Within the institution's commitment to the students is an "ethos of caring" [12, p. 146], which is part of the life of the institution. Institutions that do well with retention realize and support the importance of a vibrant intellectual community where students support each other in pursuit of learning.

2.1 Research on women and under-represented minorities in engineering

In a study of women about to graduate from a large Midwestern university's engineering program, Wentling and Camacho [18] used surveys and focus groups to identify the factors along three domains—university, family, and personal—that help and hinder women in completing a degree in engineering. Within the university domain, both the surveys and focus groups indicated that faculty could either hinder or assist students in completing their degrees. That is, faculty who taught poorly, were not motivating, or who were ineffective hindered progress while, conversely, those who were encouraging, taught well, and with whom they had good experiences assisted with degree completion. In fact, many of the other university factors mentioned reflect on faculty including hindrances, such as too much homework, a competitive environment, demanding curriculum and difficult material and helpers, such as enjoyable classes and research experiences. Beyond teaching and faculty relationships, students indicated that involvement in campus organizations and internships were also university factors that encouraged them to persist. In addition to hard work, personal factors such as study skills and perseverance contributed to degree completion along with participating in study groups and support from classmates.

In studying the risk of attrition among engineering students, Litzler and Young [19] classified engineering students from 21 institutions (including four in our data set) as being "Committed," "Committed with Ambivalence," and "At-Risk of Attrition" using demographic, in-school characteristics (e.g., class year, GPA, transfer), and student experiences and perceptions (e.g., confidence, peer interactions, faculty/TA quality, professors value students) as the predictor variables to build three models. Using only the demographic variables, they found that females are less likely than males to be in the Committed group but equally likely to be identified as At-Risk of Attrition. Adding the in-school characteristics and student experience variables to the model, they found that student experiences and perceptions explain whether men and women are Committed or At Risk of Attrition. Similarly, African-Americans are more likely to be in the Committed with Ambivalence group than Whites when only demographic variables are considered, but when experience variables are added, being African-American is no longer predictive of group membership. They conclude that there is strong evidence that student experiences and perceptions predict how committed students are to their major.

In a study at nine institutions that graduated at least 50 women engineers in 2003, Amelink and Creamer [20] noted that relationships formed with other students (getting along with others in the major, being treated with respect) are more strongly correlated with satisfaction with the engineering degree for females than males and conclude that faculty should promote positive peer interactions among their students. Godfrey and Parker [21] discussed the importance of "mates" and linking friendship relationships to a sense of belonging in engineering. Dominance of academic/task-oriented friendships was essential to success in this learning environment that was all-consuming with respect to students' time and could isolate them from other non-engineering groups. Similarly, Seymour and

Hewitt [11, pp. 298–9] noted the importance of women bonding to each other in science, math and engineering (SME) disciplines, particularly in courses where there may be very few women. They suggest that living learning communities help women form these bonds.

Brown, Morning, and Watkins [22] surveyed African-American engineering students to learn about the influence of campus climate on their graduation rates and analyzed the climate findings as they related to the selectivity of their institutions and whether the institutions were Historically Black Colleges and Universities (HBCUs) (analyzed as a group without regard to selectivity). As expected, they found a correlation between selectivity and graduation rates ranging from 50% in the high selectivity group to 29% in the less selective group. HBCUs graduation rate was 37%. They also found that students at HBCUs have a much more favorable perception of campus climate, particularly in the area of racism and discrimination, than students at other institutions, regardless of selectivity. Higher graduation rates were associated with lower perceptions of racism and higher commitment of the student to the institution [22, pp. 267–8]. In their policy implications, they suggest that "the wide disparities in African-American engineering graduation rates among institutions that appear to be academically similar are an important topic that should be thoroughly examined" [22, p. 269]. This research is a step in that direction as the institutions selected for the present study, two predominantly White research institutions and one HBCU, are in many ways similar to the comparison institutions, most of which are "Highly Selective to Very Selective" using the methodology that Brown et al. describe [22, p. 265], yet they are more successful at graduating Black students in engineering than their peers in the partnership.

2.2 Research on the outcomes of chemical engineering students

Our earlier quantitative study of ChE outcomes [23] is the only such work that disaggregates outcomes by race/ethnicity and gender simultaneously. We focus here on reviewing literature that at least addresses gender differences, which has the closest connection to our use of critical theory. R. Felder, G. Felder, Mauney, Hamrin, and Dietz [24] followed a cohort of students through an experimental course sequence in ChE at a single institution. Women entering the cohort had stronger admissions characteristics and family backgrounds more consistent with success in college than the men. They were also more motivated than the men and more likely to credit their success to help from others whereas men were more likely to credit their own ability. Some of the findings of Felder et al. have been found to generalize to engineering and Science, Technology, Engineering, and Mathematics (STEM) fields. For example, the lack of a gender gap in persistence in the Felder, et al., study is consistent with findings for engineering and STEM in the aggregate [8, 25, 26], and the tendency for men to drop out while women are more likely to switch majors in good academic standing is consistent with findings for STEM students [4, 11].

Hartman, Hartman, and Kadlowec [27] surveyed six cohorts of first-year students in engineering at a single institution. They compared the ChE women to the men and to other engineering majors. ChE women were significantly more likely than men to report a "drive to achieve" and indicate that they have good study skills. The ChE women were much less likely than ChE men to report confidence in their computer skills. They were also less likely than women in Mechanical Engineering (ME) or Electrical and Computer Engineering (ECE) to have confidence in their computer skills and to report being "technically inclined." Even in the first year, less than half of the women were satisfied with their college major. Women were significantly more likely than men to strongly agree that ChE would provide a challenging job (62% to 30%) and have respect from others (54% to 30%). Similar to men, 69% of women thought ChE would provide a well-paying job (from Table 5 of their work).

Godfrey [28] described ChE as having a less "macho" culture than other engineering disciplines which helped make it more welcoming to women. Brawner and her colleagues [29] showed that many of the women who choose ChE do so because they enjoy chemistry while simultaneously having a dislike for physics, making fields like mechanical and electrical engineering that require a lot of physics less attractive. That work explored why women choose to major in ChE and found that flexibility both within degree programs and prospective careers was the most significant factor. Other issues related to career prospects include: the expectation of being able to begin a career immediately after completing a four year degree, ease of finding a job, salary considerations, and the ability to give back to the community while making a good living.

Using a large multi-institutional dataset, Lord, Layton, Ohland, Brawner, and Long [23] described demographics and outcomes for students in ChE disaggregating by race/ethnicity and gender. Women choose and graduate in ChE at similar or higher rates than men of the same race/ethnicity. Trajectories of ChE students differ by race/ethnicity, but gender differences are small compared with the differences by race/ethnicity and the gender differences observed for engineering as a whole and in other specific engineering disciplines. Black women are especially drawn to ChE, choosing ChE at the highest rate for any race/ethnicity-gender group of engineering students so that they outnumber Black men in ChE at matriculation and six-year graduation in this data set.

In summary, this work focuses on identifying the incidence and causes of success in ChE rather than on explaining failure. While university, family, and personal factors can help and hinder women in completing a degree in engineering, we focus on factors that are in the control of the university —the workload, the extent to which the environment is competitive or collaborative, and the extent to which faculty are motivating, effective, and encouraging. Where prior research finds gender and race effects in student commitment, they are not significant when variables such as in-school characteristics and student experience are considered. The present study combines many of the best features of earlier studies—we disaggregate our findings by race and gender, we explore the impact of institutional differences on outcomes using a large multi-institutional dataset, and we let the voices of individual students speak about the role of institutional and disciplinary culture in influencing those outcomes. ChE has been shown to have a higher percentage of women than other engineering disciplines, so it is important to hear these women's narratives which can help ChE and other engineering disciplines learn how to support women's success in engineering.

3. Methods

This research builds on the earlier quantitative work of Lord, et al. [23] and incorporates both explanatory and exploratory sequential mixed-methods models in a multiphase design [30]. The phases are quantitative → QUALITATIVE → quantitative with primacy here being given to the qualitative aspects of the study. We began with quantitative analysis of the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) as it related to attraction and persistence of students in ChE by race and gender [23]. MIDFIELD [31] is a dataset with 142,222 first-time-in-college (FTIC) students matriculating in engineering and 42,383 transfer students articulating in engineering at eleven public, generally large U.S. institutions, nine of which are in the Southeastern United States. More details on the demographics of the overall database and the ChE population as well as metrics used are available elsewhere [23, 31].

Given Lord and colleagues' findings [23], we sought the voices of Black and White female students through focus groups at three MIDFIELD partner institutions. We also compared the persistence and graduation outcomes of Black and White students at the study institutions with those at the remaining MIDFIELD partners to test whether persistence and graduation outcomes were similar for Black and White women at the two sets of schools. This allowed us to frame our qualitative findings in the context of MIDFIELD schools overall.

3.1 Qualitative

The higher percentage of women in ChE compared to other engineering majors led to our qualitative study of women majoring in ChE to answer our overarching research question: *Why do women choose and remain in chemical engineering?* We initially held focus groups at two MIDFIELD institutions, one HBCU in fall 2009 and one Predominantly White Institution (PWI) in spring 2010. The selection of those institutions was related to convenience but also a belief that they would be representative of similar institutions in MIDFIELD. Together those groups included seven Black women and three White women. An additional focus group was held in fall 2011 at another PWI within the MIDFIELD partnership, in part to confirm the findings from the first two institutions as well as to include more White women who were substantially outnumbered by Black students in the first study. That group included six White women, bringing the total number of participants to 16. Students were invited to participate in the groups by a person on each campus who had access to lists of women majoring in ChE. As shown in Table 1, students ranged in age from 20 to 27 and were juniors and seniors. Five were transfer students and three were first generation immigrants to the United States. Twelve of the 16 had at least one parent with at least a four-year degree, which is relevant because parental education is the most commonly used measure of socioeconomic status [32]. Nearly half had a relative who is an engineer. Each student received $20 for her participation.

Analysis of the focus group data was assisted by Atlas.ti^{TM}, a software package for managing collection and analysis of qualitative research data. Transcripts were initially coded using a priori codes based on the interview guide and expected responses from literature and experience. In addition, quotations were coded as representing success, persistence, or mitigators to either of those. A mitigator would be expected to work against a student having a good experience or remaining in the major, for example, poor teaching quality in departmental classes. Responses were also analyzed by race and

Table 1. Demographics of focus group participants

Code	Age	Ethnicity	Transfer	Mother's highest education level	Father's highest education level	Engineers in the family?
A1	22	Black	yes	2-yr degree	grad school	yes
A2	21	Black	no	grad school	4-yr degree	yes
A3	21	Black	no	4-yr degree	high school graduate	no
A4	20	Black	no	2-yr degree	high school graduate	no
B1	23	Black (African)	yes	some college	4-yr degree	yes
B2	22	Black (African)	no	grad school	don't know	no
B3	22	Black	yes	4-yr degree	4-yr degree	no
B4	20	White	no	high school graduate	high school graduate	no
B5	21	White	yes	grad school	grad school	yes
B6	27	White (E. European)	yes	high school graduate	some college	no
C1	21	White	no	4-year degree	grad school	yes
C2	21	White	no	4-year degree	4-year degree	yes
C3	21	White	no	4-year degree	4-year degree	yes
C4	21	White	no	high school graduate	high school graduate	no
C5	20	White	no	4-year degree	4-year degree	no
C6	21	White	no	4-year degree	grad school	yes

transfer status, using the "Co-occurrence Explorer" [33, pp. 284–287] that is part of the software package, to determine if there were differences in the lived experiences of students that could be attributable to their race or transfer status, although neither was found to be an important factor. Using constant comparative analysis, [34] related codes were combined on a more conceptual level as analysis progressed; reducing the initial set of codes from 181 to 84 and then grouped into families related to the original research question.

The richness of the descriptions of the experiences shared by the students is one of the key advantages of focus group research. We use direct quotations but edit them to eliminate verbal crutches, excessive repetition, false starts, and unrelated digressions to enhance readability. Some details have been obscured to protect the privacy of the participants.

3.2 Quantitative

3.2.1 Context

Following the analysis of the focus group discussions, we queried MIDFIELD to determine if, and in what ways, the outcomes for women at the institutions where we conducted the focus groups were representative of women in chemical engineering at all MIDFIELD institutions, because, as shown below, the Selected Institutions fairly represent MIDFIELD as a whole. MIDFIELD data and corroborating data from American Society for Engineering Education (ASEE) [5] show that there is a relatively high percentage of women (approximately 35%) majoring in chemical engineering. This substantially exceeds the percentage of women in engineering as a whole (~20% nationally and ~20% in MIDFIELD). Furthermore, not only is the percentage of women high in the major, but chemical engineering attracts a disproportionate number of all women who are engineering majors. Nineteen percent of all women (and 22% of Black women) in the MIDFIELD database start in chemical engineering compared with 9% of men [23]. Similarly, 18% of engineering degrees awarded to women are from ChE compared with 8% of engineering degrees awarded to men.

The three institutions at which the focus groups were held are referred to in this study as Selected Institutions and the remaining seven MIDFIELD institutions that offer ChE are referred to as Other Institutions. We compare student entering characteristics by institution using three measures: SAT verbal scores; SAT Math scores; and peer economic status (PES)—a proxy for socioeconomic status [35, 36]. These measures are displayed for each institution in Fig. 1, normalized by the mean of the measure (e.g., PES values are normalized by the PES mean). Data markers are filled or not-filled to

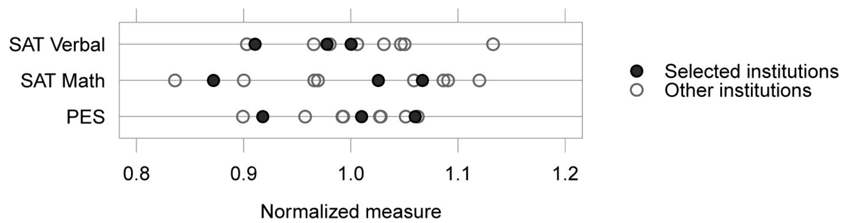

Fig. 1. Comparing institutional representativeness on three measures. A row shows the distributions of the 11 institutions on that measure.

distinguish Selected from Other institutions. We conclude that the Selected institutions as a group are representative of the 10 MIDFIELD institutions with ChE programs as a whole because the distributions of these data are not noticeably different between the two groups.

3.2.2 Metrics

The term "starters" refers to the total of FTIC students who matriculated directly in a major and those imputed to start in that major from First Year Engineering (FYE) programs. "All" includes starters as well as those who switch into the major from another major at that institution or transfer from another institution. Graduation is defined as having graduated by the sixth year from matriculation following Integrated Postsecondary Education Data System (IPEDS) standards [37]. 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 [8].

"Stickiness" has been defined as the probability of remaining in a major once it has been declared [38]. This useful metric contains richer information than other persistence metrics and allows the combination of students from FYE programs with those from direct matriculation programs. This is a way to define a pocket of success that is more holistic and conclusive. While stickiness is measured quantitatively, we also use qualitative methods in this study to explore what it is that makes a discipline sticky. It not as simple as equating stickiness with ease of success, because ChE has been described as a hard major [29].

Using similar methods to those in Lord, et al. [23] here we focus on only Black and White students in ChE. That work included Asian and Hispanic students. However, these populations are relatively small in ChE at the Selected institutions in any given year and no women identifying as Asian or Hispanic volunteered to be included in the focus groups.

4. Results and analysis

4.1 Attraction to the university and department

4.1.1 University reputation

The key reason that these women chose their schools was because of their reputations. However, the element of the institution's reputation that was most important differed depending on the school. For the women at/ the HBCU, its reputation as a high-quality producer of Black engineers as well as the intimate and cooperative environment were the critical factors as A2 describes:

> The other colleges I was looking at, none were HBCUs. After doing further research and visiting the other schools, [I decided] that I wanted to be in a smaller school, versus a really big one. And so looking at all the different schools [Institution A] and their engineering program really stood out for me the most (A2).

For those at the larger research institutions, the general reputation of the college of engineering and the perceived ability to get a good job upon graduation were the most important factors. A student at Institution B commented: "Well, I've heard a lot about the engineering school here and that was the main reason I can say I enrolled. It's very well-known and respected in the industry" (B6).

4.1.2 Attraction to the department

The reputation of chemical engineering as a discipline that is high-paying and challenging was attractive to some of the students, as was the opportunity to build on a love of chemistry combined with a dislike of physics. Similar findings have been reported elsewhere with both these students and with other MIDFIELD engineering students [29, 39]. Here, we address what makes these particular chemical engineering departments successful. The specific reasons at each institution were different, but in essence, they were due to the relationships formed through interactions with people in the departments, whether they were faculty, advisors, or other students.

As noted above, the small size of the college of engineering at the HBCU and consequently of the department allowed the students to form close relationships with their faculty and a sense that the faculty members cared about them.

> And then one of the things that I liked about chemical engineering at [Institution A] was it was a small department. So, you'll get to have that one-on-one interaction with your teachers and get to see them in your office hours and they would know your name and not be like, "are you sure you're in my class?" And, I don't know many chemical engineers that skip class, but should they, the teacher, I feel, cares enough to send you an email or ask the class, "have you seen, [A4]? Where is she? Is she okay?" And they actually care about their students in seeing them succeed, so that's one of the things I really liked about [Institution A] is the amount that they cared (A2).

Students at Institution B almost unanimously credit a particular administrator, who is also an advisor, for attracting and retaining them in chemical engineering. This same administrator recruited students to participate in the interviews. One student, who works as an Ambassador for the department described her thus:

> I give tours a lot for open houses. And I always come in and up to the chemical engineering tour. And she's [Dr. X] always there waiting, and she introduces herself to

every single person. And every time I give a tour, I talk about how she's just the best advisor, best person to run this department ever. And she's a big reason why I find that this department's so successful. And I always end up talking about her during the tour saying when you come here, she will know you by name. And you will live in her office. Any problem you ever encounter, she's there to help you with it (B5).

A transfer to Institution B describes how she might still be at her previous institution if it weren't for Dr. X's involvement in the process.

I was trying to transfer in the middle of the summer, and it was like June or July, and I called the engineering office and talked to the transfer coordinator. And he [said], "well the program's full." . . . So I called and talked to Dr. X., and she [said] just go ahead and apply. And I was talking to her through email and via the phone, and I mean I got in. I got scholarships. I probably wouldn't be here if it weren't for her. . . . So I think she's had a lot to do with a lot of people's success (B3).

At Institution C, few cite extremely positive faculty or advisor relationships. The relationships that women credit for their success in the department are with each other.

Women tend to be more social than men . . . And you know our [group] is really girls. We kind of band together and we're like "we can do this, we can get through this." We encourage each other. It's kind of crazy what happens at three in the morning with us. But we stick to it and we help each other. It's like no one gets left behind (C5).

4.2 Persistence in major

During the focus group discussions, six themes emerged related to why these women persist in the major, which we identified as: Sisterhood, Real-World Experience, Real-World Examples, Caring Faculty, Sense of Accomplishment, and "I Got This Far." These themes will be addressed in turn below.

4.2.1 Sisterhood

Listening to the women at Institution C talk about their experiences, it was remarkable that any of them were still in the major. They describe the demotivating effect of low test grades and having to "get used to failing grades not actually being failing" (C1); of having "a professor tell us that he didn't want to be there and he didn't want to be teaching us—he just had to" (C3); and of reported exam averages of 11 or 30 (out of 100). Yet, in spite of these experiences, they remain in the major, principally because they rely on each other for academic and emotional support.

I have two girls that I don't even try to open the book without them there. It's just like, we're gonna do it together and we're going to get through it. And I feel like guys with us they're so scatterbrained and all over the place. And they say—"Oh, I already got Part A done, so I'm gonna do Part D." Where I'm like, "My friend doesn't have A done yet. So I'm gonna teach her it, and then we're gonna do B together." It's just like we're very organized, and we're going to do it. And I feel like that goes back to just maybe being more of a community and doing everything together (C2).

The support for each other and the friendships they have formed is expected to carry them through to graduation and perhaps beyond.

We talk about how we all have to work for the same company when we get out, because we don't know what we're gonna do. Like that's how close we are. It's like our little Chem-E family, and like we want everyone to do well (C5).

Institution B is like Institution C in the sense of being a large research institution. And while test averages are reportedly in the 40s rather than near single digits, there is still a "cooperative spirit" among these women in an environment where they feel competition from both men and from some other women.

They [other women] can be vicious too. But there are a good handful that work together. It's really nice because you can get in a group together and be successful together. And that's who're the people I found to work with (B5).

B5 believes that one advantage of chemical engineering, relative to other engineering disciplines at Institution B that are more male dominated, is that ChE has a high enough fraction of women in the department, that it is relatively easy to find other women with the same outlook and attitude toward cooperation.

I think part of it is because there are a lot more females. Like my study groups all consist of all females and me. I know there are some people that do female-male study groups and stuff. But I've never been a part of that, so I have more females in my classes to actually be able to get together and go off. I think if I was by myself or just a couple, it's very hard to break that barrier, and, at least for me personally, to be able to approach a couple of guys and be like, "hey, you guys wanna study?" (B5)

Tarr-Whelan [40] has coined the term "30 Percent Solution" for the proportion of women in decision-making positions necessary in business and government for women to be insiders rather than outsiders in the decision making process. Similarly, these students intuitively feel the need to have a critical mass of women for support. As we have shown [23, 29], ChE in MIDFIELD and at the Selected schools meet this threshold.

As a smaller school, the cooperative spirit at Institution A was attributed more to the institution itself, rather than to chemical engineering in particular, but it was still evident.

That's one of the things I really like about Institution A is that we're really supportive of each other. Like if we run across a problem we can call each other up [and say]

I'm not really getting this. And we'll take the time to walk each other through it, versus; I know a lot of other schools that are really competitive. They'll be like, "figure it out!" and hide books in the library so that nobody can get the answer that they got. It can be really competitive, but at Institution A it's not like that. We want to succeed but we want others to be able to succeed too (A2).

These findings echo Seymour and Hewitt's [11] finding that women in Science, Math, and Engineering majors "bond" with each other more than men do [11, pp. 298–301], Felder and colleagues' [24] conclusion that women credit their success in ChE to the help they receive from others, Wentling and Camacho's [18] personal factors for women's success in engineering, and Godfrey and Parker's [21] discussion of the importance of "mates" for success in engineering.

4.2.2 Real-world experience

Work experience through co-op programs and internships was as important as friendship and camaraderie to the women remaining in chemical engineering in spite of the difficulties they faced. This is consistent with a major finding of a recent Gallup poll that "if graduates had an internship or job where they were able to apply what they were learning in the classroom, were actively involved in extracurricular activities and organizations, and worked on projects that took a semester or more to complete, their odds of being engaged at work doubled. . ." [41, p. 6].

As an engineer we get a lot of opportunities to get internships. And the people who come and talk to us about the actual engineering industry are very enthusiastic about what they do, and so it keeps us here, wanting to be in the position they're in and be actually satisfied with our job (A1).

This real-world exposure to the nature of chemical engineering work helped them to put their academic tribulations into perspective.

And because I did the [co-op], so every other semester I'm gone, and I'm doing work. And that is what keeps me here because I realize that what I'm learning in the classroom, you kind of need it. But if you don't understand everything, it's okay—you can still be awesome at your job, and you can still really like it and work in that environment. And when I graduate I'll have almost two years of experience when I'm done with the company. Realizing that I can still do this, even if I get a C in a class, is really what keeps me going. Because I study with people who have never even seen what we're designing in real life . . . . I like it because I've climbed inside of them, and I've gotten to see the heat exchanger trays and all the packing that goes in the distillation. And that's why I do it, because it's real life—huge things that you can see. But I don't understand how people would stay in it if it's just this little line on a piece of paper. I would be out in like a month if I wasn't already in—doing it hands-on (C2).

But if you present me something that I've learned in [my job], something I've learned in the proprietary technology modules, I feel like that's the chemical engineering that I've really learned and I can really take it from class to work. But as far as thermo, we've been in thermo for what, a whole year? Two different teachers. I still don't know what fugacity is. I still don't know how to apply fugacity. I have no clue what it is! But I know what a bi-reactor is. I know how it is applied in industry. I know when I learned this is how I'm gonna put it in there. Most of my chemical engineering is in biotech, biotechnology. I can figure all the other stuff out, but I feel like that's just where I shine. And I guess that's why I like it (B2).

Wentling and Camacho [18] likewise found that internships were a key factor, ranking fourth among the university factors on their survey, for students in their study to remain in engineering. Like C2, one of their focus group participants thought that the internship opportunity helped put into perspective the material learned in the classroom.

4.2.3 Real-world examples

While real world experience was critical to many of the women's desire to remain in chemical engineering, women also suggested that the use of real-world examples in class helps them understand the material better.

So it kind of helps when examples are shown, or how this could be applied, and that's when the teacher comes in. Because I mean anyone can be given a chemical engineering book, but whether or not you understand it, the teacher helps. The teacher definitely helps and they're able to pull life experiences, like, "there was this one time I was on an oil rig and this happened. We had to apply this method." And it just really helps you open your mind and expand what the concept is and understand it better (A2).

I also like when some of our professors refer to the companies in industry, or to their experience with the industries, or something that's actually related to world outside of this school. And that's sort of a positive reinforcement of some sort, because it helps me in the future, and it actually makes me interested (B6).

At Institution C, the students craved real-world examples, but did not appear to get them as much as they hoped.

So I feel like if they did application-based classes, more students would be better at it, because it's taking this large amount of work that you need to do, posting down into this, and then making it hands-on. And that's what most of us are good at, and that's why we want to be an engineer—it's because we're very good at that. So if we had more classes like that, people would understand that even though I'm not so good at the theory, I'm really good at application. And I feel like that would give everybody confidence. At least that would give me confidence (C2).

As noted earlier, C2's co-op gave her the real-world experience that kept her interest in ChE, but her observation suggests that students at Institution C who lack those direct experiences will not even have the benefit of the vicarious experience of hearing about them in the classroom.

4.2.4 Caring faculty

Seemingly more important than good teaching to these students was having a sense that faculty care about them and their success. This is consistent with another finding from the same Gallup report that "if graduates had a professor who cared about them as a person, made them excited about learning, and encouraged them to pursue their dreams, their odds of being engaged at work more than doubled, as did their odds of thriving in their well-being" [41, p. 6].

> I think it's the feeling that the faculty actually cares about you succeeding in their class. Because I get that from a lot of my teachers they're like, "what are you not getting? What concept are you not understanding? You know, could you explain it to me, let's work through a problem and see how far you can get, and then we'll take it from there." And they really just take the time to work with you, and you really get that feeling that this person really cares if I get this or not. They're not just like, "oh well, I got my degree! I hope you get yours!" (A1)

In fact, the students were willing to overlook demonstrably poor teaching when they believed that faculty members had their best interests at heart and were willing to help them understand the material.

> I had Dr. H. and I didn't particularly enjoy going to his class. But he made sure that you understood it if you wanted to know. Like if we were having a test, he would come back and [say] "I'll have a study session. You can come up to my office any time. I'll be up until X p.m. the night before a test." Like he tried really hard to accommodate you. And even though his lectures weren't particularly engaging, it's obvious that he wants his students to succeed (B3).

Just as faculty at Institution C subjected students to harsh exam grades, caring faculty seemed to be somewhat rarer at that institution, yet still important to the students, as represented by this exchange where M is the moderator.

> C5: I could go on all day about how much I like that man. He's great. First day of class, he had you write down your schedules, and then he tailored office hours to try to fit into your schedule instead of you having to move around all of your stuff to go to office hours. And he specifically said "Open door policy. Come in whenever my door is open. Feel free."
>
> M: But this sounds unusual. [participants mumble in agreement]
>
> C4: Either you don't feel comfortable, or that policy is out of the question. It's unstated and if it might be an option, I'm never comfortable.
>
> C1: Some of the professors aren't always even guaranteed to be in their office when their supposed office hours are. Actually, the one who was giving us 11 percents on the exam, you could go knock on his door at 11 p.m. at night, and he'd answer his office door and answer your questions, but that was just because it was 11 at night and we were desperate for an answer. I don't think we would have normally thought to actually check and see if he was there that late.
>
> C6: Honestly, I feel like most professors don't have an open door because they are doing research.

The students seem aware that an open door policy might be unreasonable to expect at a research university, and may be more upset that a faculty member would make such an unreasonable promise. Astin [9] notes a research orientation tends to be negatively correlated with a commitment to student development, most especially at large, public research institutions. However, he also posits that a weak institutional commitment to student development is not an inevitable consequence of a strong research orientation because there are institutions that have both. Similarly, he reports little association between research orientation and a commitment to student development by individual faculty members within the institutions. Rather, he concludes, that it is the institution's policies toward hiring faculty with a research orientation that lead to a weak commitment to student development [9, pp. 410-412]. These students appear to feel that the faculty in their department have their research prioritized ahead of their teaching and it's borne out by them feeling uncomfortable approaching faculty with a nominal open door policy.

4.2.5 Sense of accomplishment

The only area related to persistence where there was a noticeable difference between the Black and White women was the idea that graduating with a chemical engineering degree would be a point of pride and accomplishment beyond simply being able to get a good job. All of the HBCU students indicated that they liked chemical engineering specifically because it is hard, which resonates with what Stevens and colleagues [42] called the "meritocracy of difficulty" that is common in engineering. There was also a sense of wanting to set a good example for others in their family or community, a finding that corroborates that of Seymour and Hewitt [11].

> I stayed in engineering; it would be a huge accomplishment to me, but not just me. I'll be the second one. My mom was the only one to go to college in my family, and it's a long distance between me and her. And ever since I've been to college, I've gotten cousins into college, and back home, most people when they graduate high school they just stick around. They don't do anything. And so, when I go back home, I want to be a good influence to other people. And for somebody to say, I

> got out of this situation, that's another reason I do stay in. Because a lot of people where I come from they don't go to college, or if they do they don't finish, so, that's another reason I try to stay in (A3).

This idea of pride of accomplishment was discussed most often by the Black women, but may also be a part of the immigrant experience. Two immigrants, one Black from Africa and one White from Eastern Europe express similar notions:

> When I switched to chemical engineering, I just felt like that helps me do more coming from [Africa]. I mean, I didn't live in a village or remote area, but knowing people who lived in remote areas and how, just little things that we take for granted here, changes their lives back there, I wanted to be able to do something similar in that area. And so I decided to be a chemical engineer (B2).

> Well, for me it was the challenge that I liked the most, because I'm already what? 25?—I need to decide on something that would really show my abilities. Sort of move me forward, plus, the salary that chemical engineers get—it's much higher than any other out there that I had options for . . . And chemical engineering was a very good option and I just enjoy the challenge the most. That's what was my intent. To try myself in something that's really hard. I'm coming from a family; none of us ever had a high education. And now I'm pretty much first in line and I just thought that that's great opportunity for me to move up (B6).

This particular sense of accomplishment may be more generally related to an individual's sense of rising above expectations. Although the following exchange occurs between two Black immigrants (B1 and B2) and one White immigrant (B6), they particularly believe that it is their gender that explains why they are not expected to succeed in ChE. This is a manifestation of a common implicit bias that women do not belong in science/engineering [43, 44]

> B2: You become the Perry's Handbook of your family [who think you can solve any problem] . . .

> B6: It's definitely prestigious. [Participants mumble agreement.]

> B1: For a female being in it, yeah, it is, definitely.

> M: You said for a female? What makes it that different from being a man?

> B2: It gets less expected if you're a female. Even from other females. I remember I told this, lady. She was like, "what're you studying again?" I [said] chemical engineering. She [said], "Wow, it's still amazes me, some of the fields women go into." I [thought], what century are you living in?

B5 also commented on the prestige offered by a chemical engineering degree, particularly in comparison to a chemistry degree.

> When you hear someone say, what do you do? I mean, what degree are you in right now? I say chemical engineering and everyone's like, WHOA, WHOA, WHOA! It's just a completely different status [than chemistry]! I mean it's just kind of a little different. You know, you pushed yourself, and you really worked hard (B5).

4.2.6 *I got this far*

Though the five previous reasons for women remaining in the chemical engineering major are generally positive, there were some students, all of whom were at the research institutions, who indicated that they were simply "sticking it out" because they felt it was too late to change majors.

> I hate it. The only reason I'm still here is because I'm graduating in three weeks. And I hate it so much, but I have three weeks. No, I have two weeks. So I didn't really know what else I should do. I don't really wanna go to chemistry or biology, and I wouldn't be able to do as much with that. I don't really want to go to liberal arts. You can't do anything with it, and I've been in it this long. I might as well stay. And even though I hate it [said with emphasis], and I may never wanna actually be an engineer (B3).

> My friends have definitely helped keep me in here. Also I'm too stubborn to know when to quit . . . I thought about transferring first semester junior year, but that added on another year, and I'm out of state, so my student loans are high enough as it is. So I'm too stubborn to quit, and my friends were there to help me through all of the times that I didn't understand anything that I was doing [sighs] (C1).

As juniors and seniors, these students may feel that they have invested enough time in school and that the opportunity costs of switching majors or leaving school are too great. Brainard and Carlin [45] had similar findings for women in science and engineering at the University of Washington. B3 may be lost to the profession, even if she is counted as a success because she has graduated. She represents what Litzler and Young [19] call "Committed with Ambivalence," that is, students who intend to graduate in engineering but are not convinced that engineering is the right career for them. C1 again emphasizes how the relationships formed among the students at Institution C keeps them both in the major and at the institution.

4.3 *Student trajectories*

The focus groups gave us insight into why the women at these institutions persisted in chemical engineering. While the experience may not have been overwhelmingly positive for many of them, on balance, the women had sufficient incentives to continue. With these findings in hand, we investigated how the persistence of Black and White women at these institutions compared with Black and White women at the remaining institutions with the initial hypothesis that their persistence would be similar since the institutions as a group are typical of MIDFIELD institutions. Fig. 2 is a collection of time-series plots showing the number of students

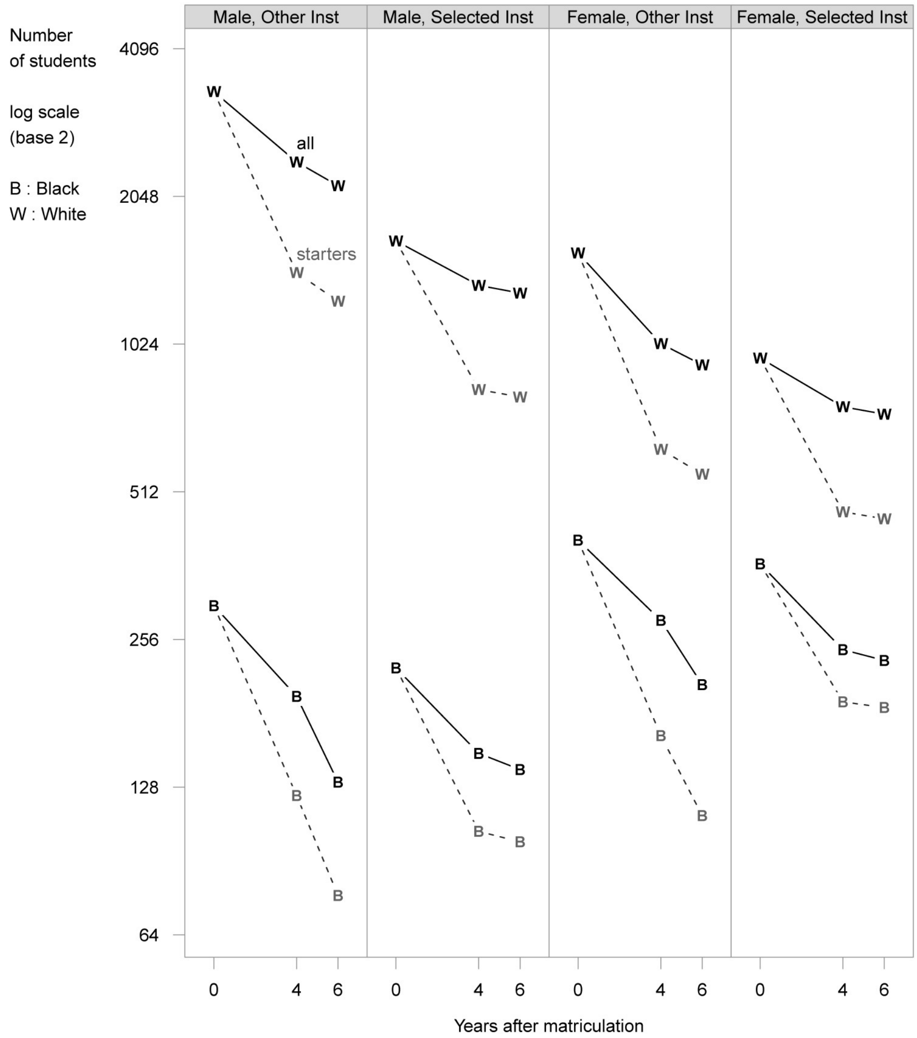

Fig. 2. Numbers of students enrolled in ChE at matriculation (year 0), four years later, and six years later. Data are disaggregated by race, gender, and group of institutions (Selected or Other).

enrolled in ChE at matriculation (0), 4 years later, and 6 years later, disaggregated by race, gender, and group of institutions. The vertical scale (numbers of students) is logarithmic in base 2 to facilitate the display of populations of widely varying size. The horizontal scale (years from matriculation) is linear. How the numbers decline over time is what we call the ''trajectory'' for a particular group of students.

Selected institutions have different trajectories with better outcomes than Other institutions. This is particularly true for Black students whose trajectory at Other institutions continues dropping between years 4 and 6, while the trajectory at Selected institutions flattens out. Thus, students who make it to Year 4 are more likely to graduate by Year 6 at the Selected institutions.

Another way to think about the success of the Selected institutions is in terms of six year graduation rate, which can only be computed for Starters. Each of the populations studied here is more successful in ChE at the Selected institutions as shown in Table 2 even though students in all groups studied

Table 2. Comparing popularity of ChE at selected and other institutions at year 1 (% of engineers choosing ChE) and completion rates at year 6 (% of ChE starters graduating in ChE)

Year 1. ChE fraction of ENG starters (%)

Group	Other	Selected	Difference
Black Female	24	29	+5
Black Male	10	10	< 1
White Female	25	27	+2
White Male	11	11	< 1

Year 6. Graduation rates of ChE starters (%)

Group	Other	Selected	Difference
Black Female	28	51	+23
Black Male	26	44	+18
White Female	35	47	+12
White Male	37	48	+11

chose ChE at essentially the same rates at the Selected and Other institutions. Thus, the higher graduation rates are not due to an elite higher-achieving population. Rather the differences seem due to features of the programs themselves.

4.3.1 Persistence

For all races separately, both genders separately, and MIDFIELD institutions aggregated, Industrial Engineering (IE) is the "stickiest" discipline while ChE ranks fourth after IE, Civil, and Mechanical or about 10 percentage points lower than IE [38]. However, for the Selected institutions, all engineering majors studied are stickier than at the Other institutions with ChE having the largest difference of 14 percentage points—61% of all students who are ever in ChE graduate in ChE in six years at Selected schools compared to 47% at Other institutions. For comparison, the difference for other large engineering majors ranges from 3 percentage points higher at Selected institutions in Computer Engineering to 11 percentage points higher in Civil Engineering. This suggests that ChE programs at these Selected institutions are particularly successful at retaining students.

Figure 3 shows the ChE stickiness for Black and White men and women at Selected and Other institutions. The dot on each row combines starters and transfers and is the number of students who graduate in ChE divided by the number of students who ever declared ChE for that population. The vertical reference line indicates stickiness in major for engineering disciplines aggregated for each race/gender combination in the two groups of institutions. For example, on the first row, the line indicates the number of White females who graduate in a family of engineering disciplines (Aerospace, Bio, Chemical, Civil, Computer, Electrical, Industrial, and Mechanical Engineering) divided by the number of White females who ever major in that specific engineering discipline at the Selected institutions.

4.3.1.1 Black and White students, male and female, are noticeably more successful in ChE

Black and White students are much stickier at the Selected institutions than the Other institutions. Students at the Selected institutions are slightly sticker, about 3 percentage points higher, than at the Other institutions for engineering as whole. For ChE, however, the differences are dramatic: 14 to 15 percentage points! All populations studied at the Selected institutions have higher stickiness in ChE than in engineering ranging from 7 percentage points for Black women to 15 percentage points for White men. At the Other institutions, White men are right at the aggregate and all other populations are below the aggregate. This suggests that the ChE programs at the Selected institutions are indeed more successful at retaining students in ChE in particular than their MIDFIELD partners.

4.3.1.2 Differences by race are much larger than those by gender

White students are stickier than Black students at all institutions. White men are slightly stickier than White women and Black women are slightly stickier than Black men, but all differences between men and women are three percentage points or fewer, indicating that the conditions at the Selected institutions are favorable for both men and women. This is consistent with the findings in Lord et al. [23] that success in ChE is racialized, but not gendered.

5. Discussion

We have shown that students at Selected institutions are more likely to persist in ChE than at Other institutions in MIDFIELD for Black and White

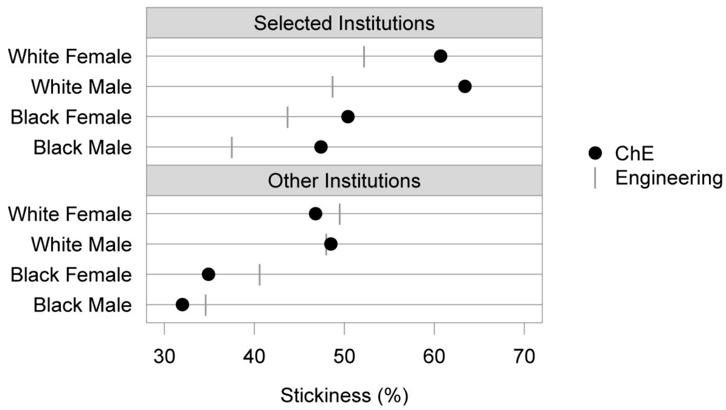

Fig. 3. Stickiness in ChE by race and gender for two groups of institutions. The short, vertical reference lines indicate stickiness in major for all engineering disciplines aggregated.

women and men. This was frankly a surprise to us as the Selected institutions for our qualitative study were chosen because they appeared to be typical among the MIDFIELD partners based on entering student characteristics as shown in Fig. 1. It was not until after the focus groups had been completed that we returned to the MIDFIELD dataset to explore the success outcomes of that subset of institutions compared to the others.

Our findings are clear that these superior outcomes are neither the result of a selection bias in favor of successful institutions nor the result of exceptional teaching. In fact, many students expressed a wish for improvements in teaching practice. We offer six reasons from our focus groups that might explain higher persistence, five of them positive. Self Determination Theory [46] posits three psychological needs that support student motivation—Competence, Autonomy, and Relatedness. Interestingly, the positive reasons found in this study to keep women in ChE are all rooted in Relatedness. The women we spoke to rely on their relationship to their peers through friendships they have formed with other women in the major, their relationship to faculty who care about their success, their relationship to the larger professional community in ChE through real-world experiences, their relationship to the profession and society through real-world examples offered in class, and their relationship to friends and family through their desire to set a good example for others. The negative example, a need to remain in ChE after investing so much time and effort, seems motivated exclusively by external regulation—a desire to avoid unpleasant consequences such as extending their time in school, potentially incurring further student loan debt.

Based on findings published in *Changing the Conversation* [47] regarding messages about engineering that appeal to young women, the predominance of relatedness in the persistence of our participants is likely indicative of the motivations of women in engineering more generally. The importance of relatedness to the persistence of women emphasizes the need to "change the conversation" not only as we recruit women to engineering, but also after they enroll to motivate them to graduate and persist in the profession. The findings and recommendations of a significant literature base both support this conclusion and offer specific strategies for acting on it. Seymour and Hewitt [11] noted the importance of relationships in the persistence of women and encouraged the creation of living learning communities. Such communities are a notable part of the environment at Institution C. Litzler and colleagues' [48] study of climate at 22 institutions, including both Institutions B and C, found that White women were 60% more likely than White men to feel like part of an engineering community and 25% more likely to feel that students help each other succeed. This may point to why community and sisterhood were so strongly felt by the students in our study and perhaps allow us to generalize our finding to White women at similar institutions. Perhaps, because the climate is better for women it is also better for men at institutions that create community. It is encouraging that there are so many paths to meeting the critical need for relatedness—some met this need by identifying caring faculty, others through their relationship with an advisor, still others through shared experiences (even unpleasant ones) with peers, and yet others by knowing that their studies were part of something bigger in the profession and in society.

Because of the importance students ascribed to the effect that knowing how classwork will be applied in the real world, strategies to bring such knowledge and examples into the classroom are particularly important for those students who are not pursuing co-op and internship opportunities. ENGAGE provides resources to improve student classroom experiences and thus retention through its Everyday Examples series (www.engageengineering.org), which includes topics pertinent to chemical engineering students such as *Real Life Examples in Thermodynamics* [49]. This also highlights the importance of pedagogies such as problem-based learning (PBL), which help students have more context for learning. ChE faculty have been among the leaders in the promotion of innovative, active, and cooperative learning [50-53]. Approaches such as cooperative learning homework teams might have additional benefits of helping students connect with other students. In this way, instructors can facilitate all students, but particularly the few women in engineering classes, in forming relationships that help them succeed. Our work extends the evidence in support of those pedagogies.

Felder and colleagues found that women were much less likely than men (18% vs. 54%) to indicate an interest in graduate school [21]. Our work suggests that this may be related to the desire some women expressed to have a terminal degree that they can use right away. It cannot be ignored, however, that this earlier finding may also be explained as evidence of a lack of commitment to a career in ChE. Our finding that some women planned to complete their ChE degree simply because they had invested too much already supports this alternative explanation—an explanation that is consistent with what Litzler and Young [19] called Committed with Ambivalence and with various reports that document the low rate of professional persistence of women engineering graduates [26, 54].

It is interesting to compare and contrast the experiences of women in ChE with those in industrial engineering which has a similarly high fraction of women. In MIDFIELD for men and women, IE is the stickiest of all majors while ChE is much lower [38]. In our study with women in IE [14], women seemed to remain in the discipline *because* of the environment while here we find that the ChE women seem to remain in the discipline *in spite* of it. Both disciplines have good career opportunities and are considered flexible enough to suit a number of different interests. Relationships with others in the discipline, both students and faculty, were reasons that women remain in both IE and ChE; however, positive and fulfilling relationships seemed to be easier to find and expect in the culture of IE, what Trytten and colleagues [55] call "inviteful engineering," than they are in ChE at these schools. Similarly, women in IE professed a passion for their discipline and claimed to "love" their major while a large fraction of the women we talked to in ChE indicate that they are sticking it out until they graduate or simply trying to prove that they can make it in a difficult discipline. This may lead to relatively more women in ChE being lost to the profession, even if they persevere and graduate.

We caution that because we did not collect qualitative data from men, we have no evidence to support assertions as to why men are successful in ChE at these institutions. However, our findings are consistent with the work of Case [56] who interviewed ChE students and found that relationships with the field, their classmates, and the lecturers were important for learning. Similarly, we did not collect qualitative data from the Other group of MIDFIELD institutions. As a result, we have no evidence that our qualitative findings collected from students who persisted would be different at the Other institutions. While our qualitative findings provide convincing evidence of why students are successful in ChE at the Selected institutions, it is possible that the Other institutions are qualitatively different in ways that we did not measure. Nevertheless, men at the Selected institutions have similar trajectories and stickiness in chemical engineering indicating that many of the same forces may be in play for both men and women in this discipline at these schools. Litzler, et al. [48] found no gender differences for African-American students on any of the climate variables that they studied indicating that it may be possible to generalize our findings in particular to African-American men.

6. Conclusion

We have identified six aspects of the experience for women in chemical engineering departments at three institutions that are related to their retention at their institutions, specifically, Sisterhood, Real-World Experience, Real-World Examples, Faculty Caring, Sense of Accomplishment, and "I Got This Far." We discovered that the three institutions at which we held the focus groups do a measurably better job at graduating Black and White men and women in chemical engineering than their similarly situated peers in MIDFIELD. We suggest that other chemical engineering departments that wish to create an environment that is successful at attracting and retaining undergraduates consider our findings and use this information to benchmark their own programs and endeavor to create a climate where women and men feel a sense of community with their peers, where faculty are perceived as caring for students' success, and where field experiences are made available to students either through co-ops and internships or related examples in class. Even ChE programs that are particularly successful in attracting and retaining women should consider our findings carefully. To the extent that "I Got This Far" is a reason for persisting in ChE, this sentiment expresses a sense of foreclosure, or unwillingness to consider other options, that is not particularly positive. By reinforcing the other perspectives, programs may be able to encourage women in ChE to focus on the more positive reasons to persist in ChE.

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