International Journal of Engineering Education Vol. 39, No. 1, pp. 142–153, 2023
Printed in Great Britain

0949-149X/91 $3.00+0.00

Longitudinal Study of Engineering Student Persistence at the University of Colorado*

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To better understand why students leave engineering study and to identify strategies to increase persistence, first-year undergraduate cohorts that entered the College of Engineering and Applied Science at the University of Colorado Boulder (CU) in seven successive fall semesters were analyzed to determine their status at the start of their second, third, and fourth years following matriculation. On average, 85% of the entering freshman were still enrolled in the college (''stayers'') as of the beginning of their 2nd year, decreasing to 75% at the beginning of their 3rd year and 70% at the beginning of their 4th year (including a very small number who graduated within three years). The rest were either enrolled in another school or college at CU (''transfers'') or had left CU altogether (''leavers''). The outcomes data were then further analyzed to correlate factors such as course performance, gender, ethnicity, residency, and freshman living community on persistence in engineering. There is a strong correlation between poor performance in courses and departure from the college, yet over half of the students who left the college had performed well (as measured by overall GPAs of 2.5 or above or by no D, F or W grades in their first year). While women persisted in the college at nearly the same rate as men, those women who left were more likely to transfer to another school or college within CU, whereas the men who left the college were more likely to leave CU altogether. These and other key findings provide guidance for retention needs and strategies.

Keywords: student persistence; retention; data analytics

1. Introduction

The United States (U.S.) and many other nations have devoted considerable attention in the past two decades to increasing the pipeline of students pursuing engineering and other STEM (Science, Technology, Engineering, and Math) degrees, as a means of improving global competitiveness and quality of life [1–4]. In response, the number of U.S. bachelor's degrees in engineering has doubled, from 74,387 in 2009 to 149,442 in 2020 [5]. However, the number of U.S. engineering degrees is expected to decline in the next few years, as freshman engineering enrollments have recently declined, with a median decrease of 3.6% in Fall 2019 (from Fall 2018) and an additional decrease of 4.1% in Fall 2020 [5].

Besides enrollments, the number of degrees is affected by student persistence [6, 7]. In the US, only 33% of recent entering engineering students graduated with an engineering degree from the same school or college within four years, increasing to 58% who graduated in six years or less [8]. Accordingly, there have been many studies on the factors that influence student persistence in engineering and other STEM majors.

1.1 Background Literature

One of the earliest studies of student persistence in STEM is described in the 1997 book, *Talking About Leaving: Why Undergraduates Leave the Sciences* [9]. The book notes that about 40% of undergraduates left engineering programs, about 50% left physical and biological sciences, and about 60% left mathematics. The losses were disproportionate among women and students of color and occurred among students with high entrance qualifications. In 2019, the follow-on book, *Talking About Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education* [10], expanded the earlier study. Both studies include national and institutional data, student interviews, and other assessments that show how traditional teaching methods and student experiences have influenced the decisions of students to leave STEM fields. Some of the key findings of the more recent study are (1) the percentage of ''switchers'' into non-STEM majors has declined from the earlier study, (2) engineering students are still less likely to switch out of STEM than are other STEM majors, and (3) female students who started in engineering or especially computer science are more likely to switch to non-STEM majors than are male students. Poor grades, loss of interest, and negative experiences are cited as the major factors contributing to student decisions to switch from STEM majors [10].

In recent years, there have also been studies that examined various factors that may predict or influence student retention in STEM. For example, Mau [11] performed a study of students who enrolled in seven universities during 2008–2013 and found that female and underrepresented minority students are less likely to declare and complete (within five years)

* Accepted 30 September 2022.

STEM majors, though improvement was seen compared to earlier studies. Not surprisingly, high-school and college grade point averages (GPAs) were positive predictors of persistence. Geisinger and Raman [7] performed an extensive review of the literature (75 prior studies examined) and identified six broad factors associated with decisions of students to leave engineering: classroom and academic climate, grades and conceptual understanding, self-efficacy and self-confidence, high-school preparation, interest and career goals, and race and gender. They also tabulated many curricular, co-curricular and extra-curricular activities as potential avenues for increasing retention. One factor is participation in undergraduate research, which has been extensively studied (e.g., [12–21]), though it is difficult to remove a potential self-selection bias from the analyses [22, 23].

A recent review of prior studies of factors influencing the persistence of college students in STEM fields used expectancy-value theory and self-determination theory as guiding frameworks [24]. It concludes that self-confidence, sense of community, competence and interest in STEM positively affect persistence and help explain observations that women are less inclined to persist in STEM than men, even with similar grades in previous STEM courses – see also [25]. A National Academies report in 2016 also discusses the concern of low completion rates in STEM college education and how the losses might be addressed [26].

One of the most comprehensive, quantitative research efforts on undergraduate student trajectories has developed and used the Multiple-Institution Databank for Investigating Longitudinal Development (MIDFIELD). As summarized in a recent review [27], it was initiated in 1996 and contains extensive data on pre-collegiate information, student pathways (majors, courses, etc.), and graduation records for over 1.6 million students from institutions across the United States (though its original focus was on schools in the southeast). This large data set allows for different disciplines to be examined (e.g., [28–31]) as well as multiple characteristics such as gender, discipline and race/ethnicity to be studied simultaneously (e.g., [28–34]). Some of the more recent work using the MIDFIELD database has included differences in performance in introductory courses [35] and time to graduation [27, 36] between engineering majors, educational data mining using machine learning [37], and advanced statistical analyses [38, 39]. The MIDFIELD research shows the value of longitudinal studies (following a population over time) over cross-sectional studies (examining a population at a specific point in time).

1.2 Objectives of Present Study

The background literature cited above, which is only a small fraction of the total, demonstrates the importance of understanding and improving persistence of STEM majors. Although improvement has been attained [10], persistence rates remain low, and several issues are unresolved. For example, recent studies on gender differences in STEM persistence show inconsistent results, as have studies on self-efficacy [24]. Moreover, prior studies are often broadly in STEM or science, whereas there is a need to disaggregate the findings among different STEM disciplines [9, 10, 24, 27]. Another need is for further research on where students go if they switch out of their original STEM majors and the differences between genders [9, 10, 24, 25, 40]. Longitudinal studies are best suited to address many of these needs [27].

To help address some of the gaps in knowledge, the present longitudinal study examines seven cohorts (entering in the fall semesters of 2010–2016) of undergraduate students in the College of Engineering and Applied Science (which includes computer science, as well as engineering majors) at the University of Colorado Boulder. The University of Colorado Boulder (CU) is a public (state-supported) university with an overall enrollment of nearly 30,000 undergraduate students, of which 19% are in the College of Engineering and Applied Science. CU Engineering is ranked 17th among public engineering colleges in the United States by *U.S. News and World Report.* Although the focus of the current study is on a single school, it is hoped that the approach and findings will be of value to other engineering schools for examining and improving student persistence around the globe. The objectives or research questions that guided the study are:

1. What are the percentages of students who persisted in engineering study into the second, third and fourth years, as well as graduated within six years?
2. Of the students who left engineering, what fraction left the university altogether versus transferred to another school or college within the university?
3. Are there gender differences in student persistence and outcomes?
4. What other factors (e.g., performance, residency, race/ethnicity, learning communities) are correlated with persistence? In particular, it is hypothesized that performance is a major factor but does not alone account for the majority of departures.
5. What are the recommendations based on the findings?

2. Methods

2.1 Data Sets

While some of the aggregated data (e.g., percentages of certain student groups that persisted from one year to the next or graduated within a specified number of years) are publicly available on the University of Colorado website (colorado.edu/oda), custom data sets were requested from the Office of Data Analytics, so that individual students could be followed during their enrollment at the University of Colorado. The Office of Data Analytics obtained the data sets from student records, including both application information and student enrollment records and transcripts. For each cohort, the data set consisted of a master spreadsheet with over 700 rows (one row per entering student) and over 50 columns of data (identifying number, gender, ethnicity, residency, courses taken, grades received, residence hall, and declared major over different semesters). In total, 5,894 entering undergraduate engineering students were followed, but only through data analysis and not surveys or interviews. The data do not include students who transferred into the College of Engineering and Applied Science from another major or institution, even though such transfer students make up a significant portion of the overall enrollment and have unique characteristics worthy of study in their own right [27].

2.2 Statistical Analysis

Standard statistical methods were used in the analysis. Most of the data are reported as percentages of students from a given group that exhibited a certain outcome. Some of the data (such as course grades or grade-point averages) are presented as average (mean) values. When comparing outcomes for different populations of students, z-tests and t-tests were performed. A two-sample, two-sided t-test [41, p. 351] was used for comparing the means of two samples (such as GPAs of men and women):

$$\mu_1 - \mu_2 = \bar{x}_1 - \bar{x}_2 \pm t_{\alpha/2}\sqrt{s_1^2/n_1 + s_2^2/n_2}, \quad (1)$$

where $\bar{x}_1$ and $\bar{x}_2$ are the measured means of the two samples, n_1 and n_2 are the sample sizes, s_1 and s_2 are the standard deviations (or, more accurately, s_1^2 and s_2^2 are the variances), $\mu_1 - \mu_2$ is the difference in the true means, and $t_{\alpha/2}$ is the t statistic or value with significance α and ν degrees of freedom:

$$\nu = (s_1^2/n_1 + s_2^2/n_2)^2 / [(s_1^2/n_1)^2/(n_1 - 1) + (s_2^2/n_2)^2/(n_2 - 1)]. \quad (2)$$

Note, for example, that a value of $\alpha = 0.1$ implies 90% confidence that the difference in the true means is within the confidence interval given by evaluating the right-hand side of Equation (1). In most of the analyses in this paper, $\nu \gg 1$.

A z-test [41, p. 326] was used when determining the significance of a difference in outcomes for two populations (such as the percentages of men and women who persisted as engineering majors into their fourth year):

$$p_1 - p_2 = \hat{p}_1 - \hat{p}_2 \pm z_{a/2}\sqrt{\hat{p}(1 - \hat{p}_1)/n_1 + \hat{p}_2(1 = \hat{p}_2)/n_2}, \quad (3)$$

where p_1 and $\hat{p}_1$ are the true and estimated proportions of population 1, p_2 and $\hat{p}_2$ true and estimated proportions of population 2, and $z_{\alpha/2}$ is the z score with significance α. Most of the results are presented as the level of confidence, $(1 - \alpha)100\%$, at which the means or proportions of two populations are statistically different (i.e., 0 is outside the confidence interval for their difference).

2.3 Theoretical Framework

A relatively simple theoretical framework for analyzing data on student outcomes is depicted in Fig. 1. The incoming students for each cohort have three potential outcomes: "stayers" (those still enrolled in CEAS, even if they switched majors within engineering), "transfers" (those still enrolled at CU but not in CEAS), and "leavers" (those no longer enrolled CU) at the start of their 2nd, 3rd and 4th years (very few students had graduated within three years and are included among the stayers or transfers). Note that this terminology differs from the terminology "switchers" (those who leave STEM or change majors) and "non-switchers" or "persisters" (those who stay in STEM or their original majors) and "transfers" (those who transfer *into* engineering) used in other studies [10, 27, 42].

Fig. 1 also shows an intermediate outcomes level in which most students are high performers (illustrated by thick arrows) but some are low perfor-

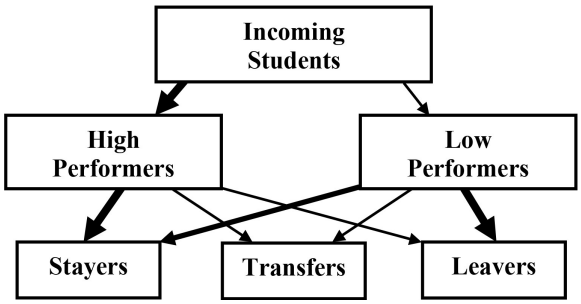

Fig. 1. Diagram of potential outcomes for incoming engineering students. The relative thicknesses of the arrows represent expected differences in fractions of students exhibiting the different outcomes.

mers (thinner arrows). The low performers are expected to more likely be "leavers", whereas the high performers are expected to more likely be "stayers". Other factors, such as gender, are also expected to affect outcomes.

3. Results and Discussion

Before proceeding with analysis of the data sets of the seven cohorts, useful background information is provided on graduation rates from the University of Colorado website (colorado.edu/oda). Starting 20 years ago, the percentage of students who entered the College of Engineering and Applied Science (CEAS) at the University of Colorado Boulder (CU) as first-year (i.e., not transfer) students and graduated from CEAS within six years has increased from 55% for those who entered in Fall 2002 to 71% for those who entered in Fall 2016, while the percentage of the same entering engineering students who graduated from CU with any major increased from 71% to 81% over the same period. These completion rates exceed those of the campus as a whole, for which 67% and 75% of those entering CU in 2002 and 2016, respectively, graduated from CU (in any major). Six-year graduation rates from the same school or college as entered at CU initially increased from 58% for those who entered in 2002 to 62% for those who entered in 2009 but then declined to 57% for those who entered in 2016, showing increased mobility.

There are remarkable differences in graduation rates between men and women from CU CEAS. First, while the six-year graduation rate (within CEAS) of male engineering students increased from 56% to 71% for those entering in 2002 to those entering in 2016, the increase for female engineering students is even more: from 51% to 72%, so that the persistence rates of men and women are now comparable. Second, the six-year graduation rate from any CU school or college of women who entered CEAS is higher for women (84% for those entering in 2016) than men (80% for those entering in 2016). These observations are examined further in the detailed cohort analysis below.

3.1 Analysis of Full Cohorts

Table 1 shows the overall results for each cohort for each year. Here, "2nd-Yr" refers to the census date of the fall semester of the students' second or sophomore year, etc. On average, for the Fall 2010 – Fall 2016 cohorts, 84.6% of the students persisted as stayers into their second year, 74.7% into their third year, and 70.3% into their fourth year. Another 6.4% were transfers into another CU school or college as of their second year, 10.6% as of their third year, and 12.1% as of their fourth year. In contrast, 9.0% had left CU as of the start of their second year, 14.6% as of their third year, and 17.6% as of their fourth year.

The general trend (normalized for increasing cohort size) is an increasing number of stayers and decreasing numbers of transfers and leavers over the seven-year timeframe. Moreover, while the largest loss occurred by the start of the second year (about 15%), there is another substantial loss between then and the start of the third year (about 12% of the *remaining* students) and a modest additional loss by the start of the fourth year (about 6% of the *remaining* students). Further data from the CU Office of Data Analytics shows that about 96–97% of the 4th-year stayers graduated from CEAS within six years. Thus, the rest of the analyses will focus on persistence after one, two and three years. The following subsections examine student outcomes based on performance, gender, underrepresented minority status, residency (in-state, out-of-state, international), and first-year residential living community.

3.2 Performance Analysis

As shown in Table 2, there is a large variation in the academic performance of the different groups of students. The average CU GPA for an entire cohort (averaged across all seven cohorts) is 3.06 (out of 4.00 maximum) after one year, 3.03 after two years, and 3.03 after three years (in contrast to some other studies, these average GPAs include the GPAs of leavers at the time they left CU). The stayers had higher grades than this average, whereas the transfers had slightly lower grades (including courses taken at CU after transferring out of CEAS), and

Table 1. Summary persistence data for all students by cohort

Year		Stayers			Transfers			Leavers		
Entered	#	2nd Yr	3rd Yr	4th Yr	2nd Yr	3rd Yr	4th Yr	2nd Yr	3rd Yr	4th Yr
Fall 2010	715	82.9%	72.9%	68.5%	6.9%	10.6%	11.3%	10.2%	16.5%	20.1%
Fall 2011	722	85.7%	77.3%	72.4%	4.3%	9.0%	10.2%	10.0%	13.7%	17.3%
Fall 2012	778	85.0%	73.1%	66.6%	5.9%	12.2%	13.9%	9.1%	14.7%	19.5%
Fall 2013	838	84.0%	72.7%	69.0%	7.8%	12.4%	13.5%	8.2%	14.9%	17.5%
Fall 2014	909	85.8%	75.8%	71.5%	7.2%	12.2%	14.2%	7.0%	12.0%	14.3%
Fall 2015	900	82.3%	73.9%	71.0%	6.9%	9.4%	11.7%	10.8%	16.7%	17.3%
Fall 2016	1032	86.7%	77.5%	73.0%	5.6%	8.7%	10.0%	7.7%	13.8%	17.0%
Average	**842**	**84.6%**	**74.7%**	**70.3%**	**6.4%**	**10.6%**	**12.1%**	**9.0%**	**14.6%**	**17.6%**

Table 2. Average GPAs for all students by cohort and outcome

Year		Stayers			Transfers			Leavers			Combined		
Entered	#	2nd Yr	3rd Yr	4th Yr	2nd Yr	3rd Yr	4th Yr	2nd Yr	3rd Yr	4th Yr	2nd Yr	3rd Yr	4th Yr
Fall 2010	715	3.09	3.09	3.14	2.85	2.86	2.90	2.15	2.23	2.26	2.98	2.92	2.94
Fall 2011	722	3.16	3.14	3.19	2.91	2.83	2.86	2.35	2.39	2.37	3.07	3.10	3.01
Fall 2012	778	3.12	3.12	3.17	2.88	2.92	2.96	2.17	2.18	2.28	3.02	2.96	3.00
Fall 2013	838	3.19	3.17	3.22	2.90	2.94	2.89	2.25	2.24	2.30	3.09	3.01	3.02
Fall 2014	909	3.11	3.14	3.18	2.76	2.89	2.91	2.35	2.29	2.35	3.03	3.01	3.03
Fall 2015	900	3.20	3.22	3.29	3.02	3.01	2.95	2.52	2.58	2.51	3.12	3.10	3.12
Fall 2016	1032	3.15	3.19	3.24	3.03	3.00	3.00	2.41	2.52	2.55	3.09	3.09	3.11
Average	**842**	**3.15**	**3.15**	**3.20**	**2.91**	**2.92**	**2.92**	**2.31**	**2.35**	**2.37**	**3.06**	**3.03**	**3.03**

the leavers had much lower grades at their departure time. The differences in GPA after three years between the stayers and transfers, and between the stayers and leavers, are significant with over 99.999% confidence. For the full cohorts, 19.1% had CU GPAs < 2.5 after one year, with a large variation by enrollment status: 14.1% for stayers, 27.7% for transfers, and 54.7% for leavers (a GPA of 2.5 is chosen for ''low performance'' because it is the value required for an intra-university transfer into CEAS).

As noted above, a higher percentage of students who left the college had GPAs below 2.5 than exhibited by the students who stayed. An alternative look at this difference is given in Table 3, where the outcomes of students with a GPA < 2.5 are compared with those for students with GPA > 2.5 (the data are averaged for the seven cohorts without weighting). The GPAs considered are the CU GPA at the time of the fall census, whether or not they were still enrolled in engineering, else at the time they left CU. By the start of their second year, 89.4% of the students with GPA > 2.5 in the seven cohorts were still in our college, compared to only 63.8% with GPA < 2.5. This difference is significant above the 99.999% confidence level. By the beginning of their fourth year, the difference was 79.0% vs 31.9%, which is also significant with over 99.999% confidence.

Perhaps of greater interest is information on the fraction of students who have performed well and yet left the college. Using the data from Table 3, it is deduced that 58% of the students who left engineering (either transfers or leavers) by the start of the fourth year had CU GPAs of 2.5 or greater after three years. *Thus, the majority of students who left the college had good performance* (at least by this measure).

Another look at performance is the outcome correlated with whether or not a student had received any D, F or W (withdraw) grades. Fig. 2 is a bar chart of the persistence data for students entering their 2nd or 4th year, split by receiving all A, B or C grades (75.4% of students) in five common first-year engineering core courses (*Calculus 1* and *2*, *Chemistry for Engineers*, *Physics 1*, and *Introduction to Computing* or *Computer Science 1*), receiving one D, F or W grade (16.5% of students) in these five courses, or receiving two or more D, F or W grades (8.1% of students) in these courses, for first-time enrollment only. The correlation is striking. By the start of their fourth year, 80.2% of students receiving all A, B or C grades in these courses were still in our college, dropping to 49.2% for those who received just one D, F or W grade and to only 19.9% for those who received two or more D, F or W grades. Again, these differences are significant with over 99.999% confidence. Nevertheless, since 75.4% of the students received all A, B or C grades, they represent over half (51%) of those who left our college.

Drilling down to individual courses, Table 4 presents the average course grade (out of 4.0) and combined percentage of D, F and W grades for the same five typical first-year courses (the data include only first-year engineering students taking these courses). The lowest grades and pass rates are in *Calculus 1*, which has been the subject of other retention studies [e.g., 43]. There is a strong correlation between performance in *Calculus 1* and subsequent persistence in engineering. On average for the Fall 2010–Fall 2016 cohorts, 62.9% of those receiving a D, F or W grade in *Calculus 1* were still in CEAS at the start of their 2nd year, compared to 88.6% of those who received an A, B or C grade. By the start of the 4th year, this gap widened to 34.6% versus 76.0%,

Table 3. Comparison of persistence by grade-point average

Analysis	GPA > 2.5				GPA < 2.5			
Point	# Total	Stayers	Transfers	Leavers	# Total	Stayers	Transfers	Leavers
2nd Fall	4768 (80.9%)	89.4%	5.6%	4.9%	1126 (19.1%)	63.8%	9.4%	26.8%
3rd Fall	4750 (80.6%)	81.7%	10.3%	8.0%	1144 (19.4%)	46.4%	12.1%	41.5%
4th Fall	4813 (81.7%)	79.0%	11.5%	9.5%	1081 (18.3%)	31.9%	15.1%	53.0%

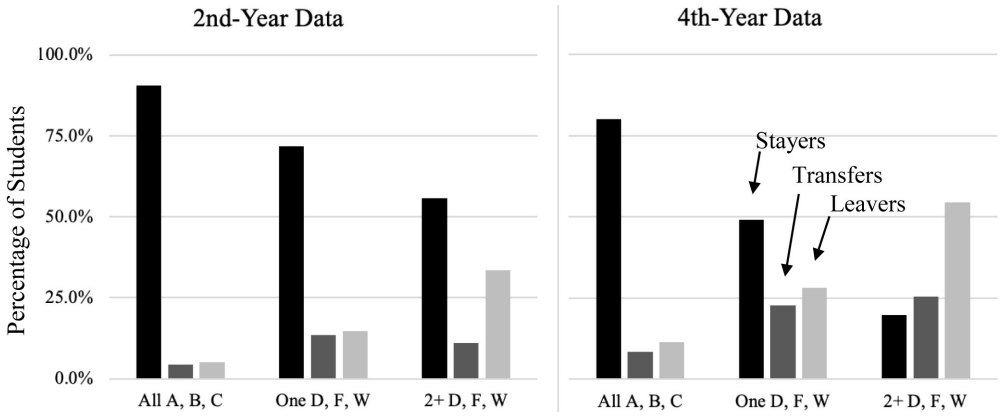

Fig. 2. Correlation of first-year course performance with 2nd-year and 4th-year persistence. The data are averaged over the Fall 2010–Fall 2016 entering cohorts and represent five common courses taken during their first year. For each data set, the three bars represent the percentages of students who were stayers (left), transfers (middle) and leavers (right).

Table 4. Average course grade (left entry) and % D, F, or W (right entry) in typical first-year engineering courses

Calc 1	Calc 2	Chem for Eng	Physics 1	Intr Comp	CS 1
2.56, 17.3%	2.65, 11.6%	2.81, 14.5%	2.91, 6.4%	3.07, 9.6%	3.35, 10.1%

Table 5. Comparison of 4th-year persistence data for men and women

Year	Men				Women			
Entered	#	Stayers	Transfers	Leavers	#	Stayers	Transfers	Leavers
Fall 2010	543 (75.9%)	68.0%	9.2%	22.8%	172 (24.1%)	70.4%	18.0%	11.6%
Fall 2011	533 (73.8%)	73.2%	9.8%	17.1%	189 (26.2%)	70.4%	12.2%	17.5%
Fall 2012	601 (77.3%)	67.7%	12.0%	20.3%	177 (22.7%)	62.7%	20.3%	16.9%
Fall 2013	606 (72.3%)	69.6%	11.6%	18.8%	232 (27.7%)	67.2%	18.5%	14.2%
Fall 2014	666 (73.3%)	72.5%	11.0%	16.5%	243 (26.7%)	68.7%	23.1%	8.2%
Fall 2015	616 (68.4%)	70.8%	9.7%	19.5%	284 (31.6%)	71.5%	15.8%	12.7%
Fall 2016	701 (67.9%)	73.2%	9.8%	17.0%	331 (32.1%)	72.5%	10.6%	16.9%
Average	**609 (72.7%)**	**70.7%**	**10.4%**	**18.9%**	**233 (27.3%)**	**69.1%**	**16.9%**	**14.0%**

indicating only a 1 in 3 chance of a student persisting in CU engineering to the fourth year, if they received a D, F or W in *Calculus 1* in their first year! Both of these differences are significant at over 99.999% confidence.

3.3 Analysis by Gender

On average, 72.7% of the entering students in the 2010–2016 cohorts are male and 27.3% female, with the percentage of women increasing from 24% in Fall 2010 to 32% in Fall 2016. As shown in Table 5, the men and women were nearly equal in their persistence in the College of Engineering and Applied Science, as the slightly higher percentage of men who stayed in the engineering college until their fourth year is significant with only 78.5% confidence. After three years, women had an average CU GPA of 3.08, compared to 3.01 for men; this difference is significant at over 99.999% confidence level. However, a striking difference is that, among those students who do leave the college, men were more likely to leave CU Boulder altogether whereas women were more likely to transfer to another school or college at CU Boulder. By their 4th year, 17% of women vs. 10% of men had transferred to another school or college within CU, whereas 19% of men vs. 14% of women had left CU. A further difference is that 71% of women who left the college had CU GPAs above 2.5 through their first three years, compared to 55% of the men who left the college, which is statistically significant with over 99.999% confidence. *Thus, a strong majority of these women were doing well in their studies (at least by this measure) and yet chose a different field.*

Of further interest is whether or not the students who left CEAS pursued another STEM field. Among the female students who transferred to another CU school or college, 58% were in a STEM major at the start of their 4th year, with the other 42% in non-STEM majors. For males, these percentages are 48% in STEM majors and 52% in non-STEM majors.

Table 6. 2nd-year and 4th-year persistence data for underrepresented minority students

Year	#	2nd-Year Retention			4th-Year Retention		
Entered	Students	Stayers	Transfers	Leavers	Stayers	Transfers	Leavers
Fall 2010	93 (13.0%)	77.4%	6.5%	16.1%	54.8%	14.0%	31.2%
Fall 2011	102 (14.1%)	82.4%	5.8%	11.8%	64.7%	13.7%	21.6%
Fall 2012	103 (13.2%)	84.5%	4.9%	10.6%	63.1%	14.6%	22.3%
Fall 2013	115 (13.7%)	75.7%	10.4%	13.9%	53.0%	19.1%	27.8%
Fall 2014	127 (14.0%)	86.6%	7.9%	5.5%	70.1%	12.6%	17.3%
Fall 2015	162 (18.0%)	80.2%	6.2%	13.6%	66.7%	11.7%	21.6%
Fall 2016	204 (19.8%)	80.9%	7.3%	11.8%	65.2%	15.2%	19.6%
Average	**129 (15.1%)**	**81.1%**	**7.0%**	**11.9%**	**62.5%**	**14.4%**	**23.1%**

3.4 Analysis of Underrepresented Minorities

Students from racial or ethnic groups that are underrepresented in engineering increased from 13.0% in Fall 2010 to 19.8% in Fall 2016. The Fall 2016 cohort includes 14.8% Hispanic/Latino, 2.9% African American, 1.9% American Indian/Alaska Native, and 0.2% Native Hawaiian/Pacific Islander. As shown in Table 6, the persistence rates of these underrepresented minorities (URMs) are lower than the general population, with 81.1% vs. 84.6% still enrolled in CEAS by their second year, on average for the 2010–2016 cohorts, and 62.5 % vs. 70.3% by their fourth year. The second-year difference is significant with 99.33% confidence, and the fourth-year difference is significant with over 99.999% confidence. The year-to-year percentages show small-number variations, but there is a general upward trend. The average CU GPA of URM students has also improved, from 2.65 after one year for students entering in Fall 2010 to 2.92 after one year for students entering in Fall 2016 – approaching the average of 3.06 for all students in this study.

3.5 Analysis by Residency

This section looks at student persistence based on their residency, divided as Colorado residents, students from other U.S. states, and international students. On average, 65% of the entering students were residents of Colorado, 28% were residents of other states, and 7% were international students (the percentage of international students increased from 1.8% in Fall 2010 to 9.5% in Fall 2016). The results are shown in Fig. 3 and show significant differences between these subpopulations. The 4th-year persistence rate is 73.4% for Colorado residents compared to only 62.5% for U.S. residents from other states. This difference, which is significant with over 99.999% confidence, is almost exclusively due to a higher percentage of non-Colorado U.S. residents leaving CU altogether. The lower retention of non-Colorado U.S. residents is also correlated with lower CU GPA: 2.95 after one year compared to 3.13 for Colorado residents. This difference is also significant at over 99.999% confidence. International students have exhibited a different pattern. Their 4th-year average persistence of 73.8% is not significantly different than that of Colorado residents (73.4%), but they have a much higher likelihood of leaving CU altogether (20.0% versus 14.6%), which is correlated with a lower CU GPA (2.82 for international students versus 3.09 for Colorado residents after three years).

3.6 Analysis by Residential Community

A review [7] of prior work identified co-curricular experiences as a possible means of improving stu-

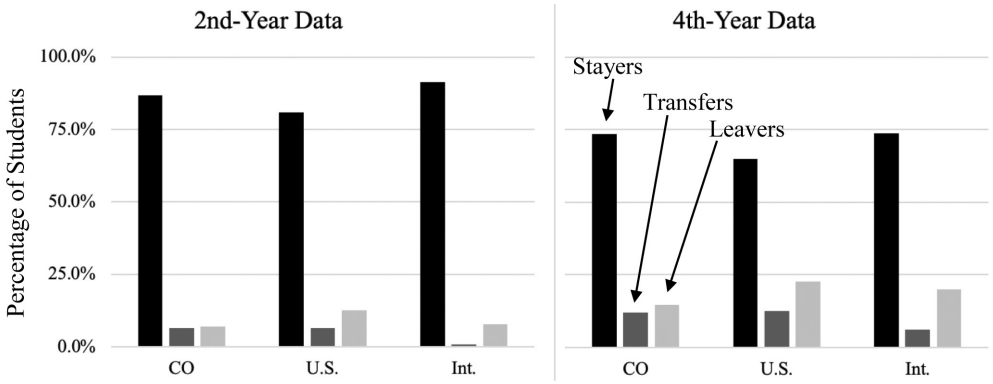

Fig. 3. 2nd-year and 4th-year persistence data for Colorado residents (CO), U.S. residents from states besides Colorado (U.S.) and international students (Int). For each data set, the three bars represent the percentages of students who were stayers (left), transfers (middle) and leavers (right).

dent persistence. As one type of co-curricular experience, residential learning communities and their correlation with persistence were examined in the current study. On average, 12.4% of the entering freshmen in the Fall 2010–Fall 2016 engineering cohorts at the University of Colorado lived in the Andrews Hall Residential College during their freshman year, 36.2% lived in the Engineering Quadrangle Dormitories, and the rest lived off campus or in campus residence halls that were not residential learning communities. Andrews Hall is an academic living-and-learning community with staff and peer support. The students in Andrews Hall primarily consist of participants in the Engineering Honors Program. The Engineering Quad is a complex of four dormitories with primarily engineering and some science students. It provides academic-support services but not as extensive as for the students living in Andrews Hall.

As seen in Table 7, the second-year persistence rates are higher for both Andrews Hall (91.7%) and the Engineering Quad (87.5%) than for the entire population (84.6%). These differences are significant, with over 99.999% confidence for Andrews Hall and at the 99.56% confidence level for the Engineering Quad. The students in Andrews Hall demonstrated higher academic performance (3.33 first-year average CU GPA) compared to the general population (3.06 first-year average CU GPA), which also is correlated with improved persistence. The students in the Engineering Quad performed similar (3.07 first-year average CU GPA) to the general population. By the start of the fourth year, the difference in persistence had increased for Engineering Quad students (74.5% vs. 70.3%) and for Andrews Hall students (78.0% vs. 70.3%). These differences in persistence are significant with over 99.9% confidence. Starting in Fall 2015, a small program for underrepresented students moved from Andrews Hall to the Engineering Quad, so only Engineering Honors students were then living in Andrews Hall; the persistence is very high for the Fall 2015 and Fall 2016 cohort students who lived in Andrews Hall. Note, however, that there is a selection bias in that students living in Andrews Hall chose to apply and were selected in a competitive process. In contrast, while students self-selected the Engineering Quad, there was not a competitive process and their average performance metrics are similar to the general population.

4. Discussion

The University of Colorado data on six-year graduation rates support prior observation of higher persistence rates of engineering students than many other majors (e.g., [9, 10, 27, 44]), though engineering has a lower replacement rate (fewer students transferring into engineering from other majors) and so may have a smaller ratio of graduating to entering students in a given year [44]. The strong correlation between academic performance and persistence in the present study supports prior work that also showed that college grades are positive predictors of student persistence in engineering and other STEM fields (e.g., [7, 10, 11, 35]). However, the present findings that 58% of the students who left CU engineering had grade-point averages above 2.5 out of 4.0, and 51% received no D, F or W grades in five common first-year courses, is consistent with the hypothesis that poor academic performance accounts for less than half of the departures.

The current finding that the overall persistence of female undergraduates and engineering is similar to their male counterparts support recent findings from the MIDFIELD data base [27]. It is in contrast with several earlier studies that found that women were more likely to leave engineering and other STEM fields (e.g., [7, 9, 11, 24, 25, 43]). Moreover, female engineering students who switched into other majors at the University of Colorado were more likely to choose other STEM fields than did male students, which is counter to a recent national study that concluded that women are more likely than men to switch to non-STEM majors from engineering and computer science [10].

Table 7. 4th-year persistence data for students living in Andrews Hall or Engineering Quad in their first year. At the very bottom of the table are the averages for the start of the 2nd year

Year	Andrews Hall				Engineering Quad			
Entered	#	Stayers	Transfers	Leavers	#	Stayers	Transfers	Leavers
Fall 2010	115 (16.1%)	69.6%	7.8%	22.6%	247 (34.5%)	72.9%	9.3%	17.8%
Fall 2011	134 (18.6%)	74.6%	9.0%	16.4%	277 (38.3%)	77.3%	12.3%	10.5%
Fall 2012	97 (12.5%)	72.2%	12.4%	15.5%	320 (41.1%)	72.8%	11.6%	15.6%
Fall 2013	111 (13.2%)	71.2%	10.8%	18.0%	281 (33.5%)	76.5%	11.7%	11.7%
Fall 2014	90 (9.9%)	81.1%	10.0%	8.9%	304 (33.4%)	75.3%	13.8%	10.9%
Fall 2015	78 (8.7%)	88.5%	3.8%	7.7%	334 (37.1%)	75.4%	9.6%	15.0%
Fall 2016	81 (7.8%)	88.9%	6.2%	4.9%	363 (35.2%)	71.6%	11.9%	16.5%
Average	**101 (12.4%)**	**78.0%**	**8.6%**	**13.4%**	**304 (36.2%)**	**74.5%**	**11.5%**	**14.0%**
2nd-Year	**101 (12.4%)**	**91.7%**	**3.0%**	**5.3%**	**304 (36.2%)**	**87.5%**	**5.9%**	**6.7%**

A provocative early study by Felder et al. [40] of gender differences in five cohorts of chemical engineering students at North Carolina State University also observed that the percentage of women leaving the program by their fourth year was not significantly less than that for men, but the women were much more likely to transfer into a different major while the men were more likely to drop out of school or be placed on academic suspension, similar to the current findings. The study also surveyed the students and found that the women, on average, had lower confidence and higher anxiety than the men in the study, even though the academic preparation and first-year performance of the women were equal or greater than those of the men. The authors proposed several social factors or obstacles faced by the women and provided useful recommendations for addressing these issues, such as more role models, mentors and cooperative learning [40]. While the current work did not survey students on why they left engineering, the finding that women were more likely to transfer to another major, even with better academic performance than men, is consistent with the view of lower confidence, lack of a supportive community, and loss of interest cited previously (e.g., [7, 10, 25, 40]), as well as described by expectancy-value and self-determination theories [24]. On the other hand, the higher likelihood of men to leave the university altogether is consistent with lower academic performance.

The higher likelihood of out-of-state domestic and international students to leave the university altogether is also aligned with lower academic performance of these groups, though it may also be affected by personal or financial factors. The international students are much less likely to transfer from engineering to another major, however, which might reflect sponsorship of their studies specific to engineering.

The present longitudinal study of engineering student persistence is focused on outcomes data and correlations. Coupling these data analytics with interviews and surveys could help answer why students from different groups or with different experiences exhibit different outcomes as stayers, transfers or leavers. Along these lines, the recent study of Brent et al. [42] presents a card-sorting method to shift the students' focus to their own experiences. This method is expected to yield insights on why students chose engineering majors and why they have persisted in or switched out of these majors.

5. Recommendations

Based on the findings from this longitudinal study of undergraduate student persistence in the College of Engineering and Applied Science at the University of Colorado Boulder, the following recommendations were made to the college administration and are expected to have general relevance to many other engineering colleges in the U.S. and other countries:

A. Efforts to build community and provide academic support pay off and should be continued. Retention strategies should be continued over all four (or more) years, with a particular focus on the first two years, when students are most likely to leave school or switch majors.

B. Since just over 50% of the students who left engineering had good academic performance, while the remainder did not, strategies to improve retention should include a mix of efforts to improve academic performance (e.g., tutoring, study guidance, etc.) and to improve affinity with the university and engineering study (community building, peer and industry mentors, etc.). As recently reviewed [24], student interest is a key factor in STEM retention. While pre-collegiate interest can be cultivated through advertising and K-12 outreach, it is recommended that engineering college students participate in co-curricular experiences such as internships and industry nights to generate (or at least assess) affinity with the discipline. In addition, providing an opportunity for students to retake key courses without delaying a year, is recommended. One such possibility, which has had a high success rate at CU, is a "second-chance" short course offered soon after the semester ends [45].

C. Different retention strategies may be recommended for men and women, such as more emphasis on course performance and academic support for men with low performance and at risk to leave the University and more emphasis on building community, self-confidence, and interest in engineering for women who are at risk for transferring to other majors.

D. A dual emphasis on recruitment and retention of underrepresented minorities should be continued and are likely synergistic (students are more likely to succeed and persist if they are in a well-represented community of peers, and prospective students are more likely to enroll when they observe such a community).

E. Academic learning communities are recommended, though additional studies are needed to tease out their direct contribution to persistence versus the students who selected them having stronger affinity and commitment to engineering.

F. Different retention strategies are suggested for out-of-state and international students, who, on average, have lower GPAs, including both academic support and providing them with community.

6. Conclusions

A longitudinal study was performed on the persistence of undergraduate students entering the College of Engineering and Applied Science (CEAS), which includes both computer science and various engineering disciplines, at the University of Colorado Boulder (CU). Detailed analyses of 2nd-year to 4th-year persistence were performed for the seven cohorts entering Fall 2010–Fall 2016. The students were then categorized as ''stayers'' who remained enrolled in CEAS, ''transfers'' who switched to a major outside CEAS at CU, and ''leavers'' who left CU altogether without a degree. Key findings in light of the stated objectives (Section 1.2) include:

A. Six-year graduation rates within CEAS increased over time, from 55% of those entering in Fall 2002 to 71% of those entering in Fall 2016 (Section 3).

B. Students who left the engineering college were more likely to leave the University of Colorado altogether (18% of the students by the end of their fourth year) than transfer to another major (12% by the end of their fourth year – see Section 3.1).

C. Persistence and graduation rates of women in engineering have improved so that they are now essentially equal to that of men, but women are more likely than men to transfer to another school or college within CU (17% vs. 10% transfers after three years) while men are more likely than women to leave CU altogether (19% vs. 14% leavers, after three years) – see Section 3.3. Moreover, women who left the CU engineering college are more likely than men to have exhibited high performance.

D. There is a strong correlation between performance and persistence. For example, 80% of students receiving all A, B, and C grades in key first-year courses persisted in CEAS into their 4th year, compared to only 49% of those receiving one D, F, or W grade and 20% of those receiving two or more D, F, or W grades (Section 3.2). Despite the strong correlation between performance and persistence, over half of the students leaving CEAS were in good academic standing (for example, 55% of men and 71% of women who left CEAS by the start of their 4th year had GPAs > 2.5).

E. Persistence and performance of underrepresented minority students have improved over time, as has their representation among the entering cohorts (Section 3.4).

F. Students of different residencies have different persistence patterns. U.S. out-of-state students transfer to other majors at about the same rate as do Colorado residents but are much more likely to leave CU altogether, whereas international students are less likely to change majors (perhaps due to sponsorship restrictions in some cases) but are more likely to leave CU than Colorado residents (Section 3.5).

G. Residential academic communities have a strong, positive correlation with student persistence (Section 3.6). The very high persistence in the Andrews Hall Residential College is likely due, in part, to the competitive application process as well as academic and social programming. However, the Engineering Quad dormitories are first-come, first-serve (no competitive application), and the students in these dormitories performed about the same as the full population and yet had significantly higher persistence.

Acknowledgements – The authors thank Emily Mohney, Riley Shore, and Melissa Velisek for assisting with a portion of the data analysis while they were undergraduate research assistants on the project.

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