Demographic Factors and Academic Performance: How Do Chemical Engineering Students Compare with Others?

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Abstract

Using the Southeastern University and College Coalition for Engineering Education (SUCCEED) longitudinal database (LDB), demographics and academic performance measures of undergraduate chemical engineering students were compared with other engineering and non-engineering students. The LDB includes data from nine institutions spanning 13 years, allowing the study of academic performance of students within chemical engineering and elsewhere throughout their undergraduate careers.

I. Introduction

It seems intuitive that undergraduate engineering students, by virtue of admission and course requirements, should rank particularly high in mathematical and analytical skills when compared with the non-science majors. Although it is commonly assumed, it is not obvious that significant differences exist between chemical engineering and other engineering students, nor is it clear how chemical engineers compare with regard to factors such as demographic background or academic performance. Furthermore, to our knowledge, no studies have yet investigated these differences across two or more institutions, thus limiting findings to institution-dependent conclusions.

In previous work[1,2], we performed cross-institutional studies to determine the effects of various factors on graduation and retention of engineering undergraduates. Our results demonstrated that SAT math scores, SAT verbal scores, high school GPA, gender, ethnicity and citizenship all play a significant role in both engineering student graduation and retention rates. Given that these factors have been shown to be important to success in engineering, it is interesting to see how chemical engineering students compare to other engineering groups, as well as non-engineering majors. As in previous work, our investigation spanned several institutions and tens of thousands of undergraduate students enrolled within the last 15 years, supporting the generalizability of our results. This study provides important context for other work that studies the performance of chemical engineering students.

II. Data Collection

Our study uses the Southeastern University and College Coalition for Engineering Education (SUCCEED) longitudinal database (LDB) [3,4,5]. The LDB contains data from eight colleges of engineering involving nine universities: Clemson University, Florida A&M University, Florida State University, Georgia Institute of Technology, North Carolina A&T State University, North Carolina State University, University of Florida, University of North Carolina at Charlotte and Virginia Polytechnic Institute and State University. Since the University of North Carolina at Charlotte does not have a chemical engineering degree program, it was excluded from this study. SUCCEED is an ongoing project, and the LDB continues to be updated as data become available. As of the current study, the LDB contained demographic, entrance, term and graduation records of all undergraduate students in these institutes from 1987 through 1998 (and for some institutions, through 2000). This represents approximately 1/12 of the undergraduate engineering population of the United States [6,7]. While the LDB contains data on transfer students as well as first-time-in-college (FTIC) students, this study is limited to FTIC students only.

The LDB contains the student major encoded in a 6-digit “Classification of Instruction Programs” (CIP) code. This code is used by all SUCCEED institutions, and permits us to follow the flow of undergraduate students as they change majors, whether between chemical engineering and other engineering subfields or to majors outside engineering. Our demographic and performance comparisons classified the students according to their final major.

Among the demographic information available, we focused on gender and citizenship. Students were placed in one of three citizenship categories: citizens, resident aliens, and non-citizens. This information was available for virtually every student record. The demographic comparisons were done for all students enrolled as freshmen in 1987 or later, and graduated by the last term in the LDB.

Entrance records provided us with baseline academic data such as student SAT scores (both math and verbal) and high school GPA. While generally complete, one university lacked high school GPAs, while two others lacked both SAT scores and high school GPAs. These institutions were not included in the analysis on their missing variable(s).

Finally, term and graduation data permit us to examine performance indicators such as the number of times a student changed major, average semester hours, cumulative semester hours, number of semesters enrolled, time to graduation, and final cumulative GPA. This information was complete for all institutions and virtually every student record.

III. Results

Our comparisons include all students who matriculated to the University as a freshman and graduated by the end of the LDB records. In the first analysis, we examine the flow of students between chemical engineering and other disciplines. In the second analysis we provide a summary of demographic differences between chemical engineering students, other engineering students, science majors and non-science majors. In the third analysis, we determine significant differences in academic admission and University performance measures among these groups.

A. Student Flow

Overall student flow between engineering and non-engineering disciplines is summarized in Table 1. Student migration from engineering to non-engineering disciplines is shown in Table 2, and the converse migration from non-engineering to engineering fields is displayed in Table 3. Finally, student flow among engineering subfields is shown in Table 4. In each table, the columns represent the initially chosen major, derived from the first CIP that establishes a student's major as more specific than general engineering or general studies. Since this may occur at the end of the freshman year, the overall graduation rates reported here are higher than the graduation rates for freshman cohorts that are commonly reported. Each row shows the percentage of students with an initially chosen major, who graduated in a (possibly different) given major. The tables summarize the flow of all graduating undergraduate students in all included SUCCEED institutions over the time period of the study (97,688 students overall), making small differences between groups quite significant.

From Table 1, we see that engineering disciplines lost both a far greater number (4697) and percentage (22.7%) of students to non-engineering fields than non-engineering fields lost to engineering (2245, or 2.9%). Moreover, Table 2 shows that chemical engineering lost a greater percentage of its students to non-engineering disciplines (27.2%) than any other engineering subfield (16.3 - 24.5%). In fact, when the results of Table 2 are combined with those of Table 4, it reveals that chemical engineering lost the greatest percentage of students to all other fields (44.6%) as compared to other engineering subfield (24.4% – 42.3%). In addition, every engineering subfield lost the fewest or second-fewest percentage of students to chemical engineering than other engineering subfields (migration to chemical engineering from other engineering subfields was low). The conclusion that chemical engineering graduates tend to begin their academic program in chemical engineering or the physical sciences is not surprising. This observation is likely related to the discipline's chemistry requirements, which appear early in the degree program and are more extensive than the other disciplines, excepting a few of the physical sciences. Thus, the chemistry requirements serve to 'lock-out' students from most other majors.

Table 1: Overall student flow between engineering and non-engineering fields. Values are given as raw number (percentage). The total number of students studied was 97,688.

BEGIN ***GRAD***	*All Engineering Fields*	*All Non-Engineering Fields*
All Engineering Fields	16031 (77.3%)	2245 (2.9%)
All Non-Engineering Fields	4697 (22.7%)	74715 (97.1%)
Total	20728 (100.0%)	76960 (100.0%)

On the other hand, the non-engineering disciplines to which chemical engineering students migrate vary substantially from the other engineering subfields. In particular, while the other engineering subfields showed the highest movement toward business, chemical engineering students transferred most frequently to the physical sciences. In fact, chemical engineering had the second lowest loss to business (just slightly greater than computer engineering). It is interesting that the link between the physical sciences and chemical engineering was not unidirectional. Table 3 indicates the physical sciences lost a greater percentage of students to chemical engineering (2.6%) than any other engineering subfield (0.2% - 2.0%).

Table 2: Student flow from engineering to non-engineering fields. Values are percentage of students beginning in a given subfield that graduate in a given non-engineering discipline. The total number of beginning engineering students was 20,728.

BEGIN / ***GRAD***	*Chemical*	*Civil*	*Computer*	*Electrical*	*Industrial*	*Mechanical/ Aerospace*	*Other Engineering*
Biology	4.0	1.0	0.9	1.2	0.5	1.2	1.7
Business	4.3	6.0	4.1	4.9	9.4	6.6	5.5
CIS	0.9	0.6	7.7	3.1	0.7	1.6	1.5
Physical Science	8.2	1.0	0.9	0.8	0.4	1.5	2.2
Social Science	1.8	2.3	2.1	2.0	1.2	3.1	2.0
Other Non-Engineering	8.0	11.0	2.7	8.5	4.1	10.1	11.7
Total	27.2	21.9	18.4	20.5	16.3	24.2	24.5

Table 3: Student flow from non-engineering to engineering fields. Values are percentage of students beginning in a given non-engineering discipline that graduate in an engineering subfield. The total number of non-engineering students was 76,960.

BEGIN **GRAD**	*Biology*	*Business*	*CIS*	*Physical Science*	*Social Science*	*Other Non-Engineering*
Chemical	0.3	0.1	0.2	2.6	0.1	0.3
Civil	0.4	0.2	0.9	0.9	0.3	0.4
Computer	0.0	0.0	2.8	0.2	0.0	0.0
Electrical	0.1	0.1	2.9	1.6	0.1	0.2
Industrial	0.5	0.9	1.7	1.2	0.2	0.3
Mechanical/ Aerospace	0.4	0.2	1.0	1.8	0.1	0.3
Other Engineering	0.6	0.3	0.6	2.0	0.3	1.2
Total	2.3	1.8	10.2	10.3	1.0	2.7

Table 4: Student flow among engineering subfields. Values are percentage of students beginning in particular subfields that graduate in any (possibly the same) subfield. Total number of beginning engineering students was 20,728.

BEGIN ***GRAD***	*Chemical*	*Civil*	*Computer*	*Electrical*	*Industrial*	*Mechanical/ Aerospace*	*Other Engineering*
Chemical	55.4	1.0	0.4	1.1	0.5	1.2	1.7
Civil	2.9	66.3	1.6	2.5	2.6	4.3	3.4
Computer	0.4	0.2	60.9	1.7	0.2	0.6	0.6
Electrical	1.6	1.6	12.5	62.9	1.4	3.3	2.1
Industrial	5.4	3.1	4.3	4.6	75.6	4.8	3.1
Mechanical/ Aerospace	3.0	3.6	1.8	4.2	2.6	57.7	4.9
Other Engineering	4.1	2.4	0.2	2.4	0.8	3.9	59.8
Total	72.8	78.1	81.6	79.5	83.7	75.8	75.5

B. Demographic Differences

In all demographic and performance comparisons, we divided the graduated students among those in chemical engineering (CHE), other engineering subfields (OENG), science fields (SCI) and non-science disciplines (NSCI). Differences in gender and citizenship are presented in Table 5 and Table 6, respectively. While CHE, OENG, SCI and NSCI groups showed very similar patterns for citizenship, they had strikingly different male/female ratios.

1) Citizenship. Citizens represented, by far, the majority of students, followed by non-citizens and then resident aliens. Interestingly, the percentage of resident aliens was highest among CHE, slightly above OENG but over triple the percentage in SCI and *twelve times* the percentage in NCSI.

2) Gender. The percentage of females in CHE was substantially lower than the percentage of males (36.25% vs. 63.75%), although the ratio was much higher than in OENG. The difference was much less marked in OSCI, but actually reversed in NCSI. The actual percentages varied substantially between schools, but the trends were consistent.

Table 5: Difference in citizenship among CHE, OENG, SCI and NSCI undergraduates.

GROUP / ***CLASS***	*CHE (%)*	*OENG (%)*	*SCI (%)*	*NSCI (%)*
Citizen	95.83	95.38	96.24	97.62
Non-Citizen	2.83	3.37	3.32	2.27
Resident Alien	1.33	1.25	0.44	0.11

Table 6: Difference in gender among CHE, OENG, SCI and NSCI undergraduates.

GROUP / ***GENDER***	*CHE (%)*	*OENG (%)*	*SCI (%)*	*NSCI (%)*
Female	36.25	20.49	44.47	56.97
Male	63.75	79.51	55.53	43.03

B. Academic Differences

We investigated the following academic characteristics (or *variables*) among the three groups: SAT verbal and math scores, high school GPA, time to graduation, cumulative GPA, number of major changes, cumulative semester hours, and average semester hours. Our questions were simple:

(1) Do CHE, OENG, SCI and NSCI differ in any of the variables?
(2) On which variable(s) do CHE, OENG, SCI, and NSCI differ?
(3) For a given variable, to what extent do CHE, OENG, SCI, and NSCI differ?

The first question was answered by a multivariate omnibus test. A Shaffer-Holm procedure was used to answer the second and third questions: An ANOVA was used to identify the variable(s) on which the three groups differ, and pair-wise comparisons among the three groups on the identified significant variables were performed to determine the extent of their differences.

1) Multivariate Omnibus Test

A multivariate omnibus test was done first to determine whether there is an overall group effect. Its null hypothesis is that the three groups do not differ in any of the nine variables. The test was done using SAS 8.1 procedure for General Linear Models (PROC GLM) through a Multivariate Analysis of Variance (MANOVA) with the group (CHE, OENG, SCI and NSCI) as the between-subjects factor and the nine academic characteristics as dependent variables. The MANOVA test criteria and F approximations for the hypothesis of no overall group effect using Pillai's Trace are shown in Table 7. To protect individual and institutional privacy, the SUCCEED universities have been randomly assigned a letter from A – I, and the degrees of freedom related to Pillai's trace have been omitted. The null hypothesis is rejected with $p < 0.0001$ for every institution, providing strong evidence for us to conclude that the CHE, OENG, SCI and NSCI groups differ significantly in at least one of the academic characteristics.

Table 7: Pillai's Trace of p-values for the Multivariate Omnibus Test.

UNIVERSITY	***Pillai's Trace, p-value***
A	F=193.61, p<0.0001
B	F=32.62, p<0.0001
C	F=100.93, p<0.0001
D	F=93.69, p<0.0001
E	F=50.50, p<0.0001
F	F=95.10, p<0.0001
G	F=218.31, p<0.0001
H	F=95.28, p<0.0001

2) ANOVA on individual variables

The multivariate omnibus test having definitively shown that the four groups differ on at least one variable, we next determined which of the variables is significant. This is done with an ANOVA on the variable. For a given variable, the null hypothesis is that the four groups do not differ on that particular variable.

The ANOVA p criterion was set as 0.05 for all variables tested. The ANOVA F tests on individual variables give $p < 0.0001$ for all schools combined, and $p < 0.0001$ for most of the individual schools. We note that in every case $p < 0.05$, giving us sufficient evidence to conclude that the four groups differ on each academic characteristic.

3) Pair-wise comparison among groups

To determine the extent of the variation among the three groups, each academic variable was subsequently tested using pair-wise comparisons. The Shaffer-Holm procedure was used to control the family-wise error rate for each of the families of pair-wise comparisons. That is, for each of the nine families of pair-wise comparisons, the test statistic and p values were ranked from the smallest to the largest in terms of the p values, resulting in six stages. The p value criterion was $\alpha=.05/3=.0167$ for the first four stages, $\alpha=.05/2=.025$ for the fifth stage and $\alpha=.05$ for the sixth stage. A specific null hypothesis was rejected for any p-value $< \alpha$.

Descriptive statistics on the nine variables as a function of group are presented in Table 8. Pillai's Trace indicates a significant difference among the four groups. Means and standard deviations of the variables are listed with a superscript attached to each mean. Means with different subscripts within the same row indicate the groups are significantly different in that variable. It is interesting to note that for every variable, CHE students differed significantly (in a statistical sense) from not only SCI and NSCI groups, but also their OENG counterparts.

1) *SAT math score:* CHE majors had significantly better SAT math scores than all other groups.
2) *SAT verbal score:* CHE majors had better SAT verbal scores than all other groups. In particular, the verbal scores for CHE majors were much better than those of NSCI majors.
3) *High school GPA:* CHE majors had better high school GPAs than all other groups.
4) *Time to graduation:* CHE students took significantly more time to graduate than both SCI and NSCI groups, but required less time to graduate than OENG students.
5) *Cumulative GPA:* CHE majors had significantly higher cumulative GPAs than OENG, SCI and NSCI majors.
6) *Number of changes of major:* CHE majors changed major significantly fewer times than OENG, SCI and NSCI majors.
7) *Semesters to graduation:* CHE students took an average of two more semesters to graduate over their SCI and NSCI counterparts, but required about one semester fewer to graduate than OENG students.
8) *Cumulative semester hours:* CHE students took significantly more semester hours, in total, to graduate, than both SCI and NSCI students, but required fewer semester hours to graduate

than OENG students.
9) *Average semester hours:* CHE students took slightly fewer hours each semester, on average, than OSCI, SCI and NSCI students.

Pair-wise comparisons for individual institutions mimic these results.

Table 8: Pair-Wise Comparisons Among CHE, OENG, SCI and NSCI Groups

Variable	Statistic	CHE	OENG	SCI	NSCI
*SAT math score	M SD	645.92^a 82.29	635.88^b 83.83	609.11^c 96.20	533.16^d 92.20
*SAT verbal score	M SD	533.96^a 86.73	517.34^b 87.62	519.66^b 95.66	490.06^c 87.45
**High School GPA	M SD	3.72^a 0.36	3.56^b 0.41	3.57^b 0.47	3.31^c 0.52
Time to Graduation	M SD	53.88^a 8.88	55.90^b 10.24	51.77^c 11.22	51.82^c 10.88
Cumulative GPA	M SD	3.17^a 0.49	2.98^b 0.55	3.04^c 0.68	2.97^d 0.54
Number of Major Changes	M SD	0.63^a 0.76	0.95^b 0.83	0.89^c 0.92	1.29^d 1.03
Semesters to Graduation	M SD	13.04^a 4.07	13.87^b 4.35	11.69^c 3.62	10.94^d 2.62
Cumulative Semester Hours	M SD	163.35^a 38.42	168.87^b 42.12	146.05^c 36.29	136.11^d 26.10
Ave Semester Hours	M SD	13.01^a 2.34	12.60^b 2.22	12.84^c 1.99	12.68^d 1.75

Note: Means within the same row with different superscripts are significantly different controlling the family-wise error rate.

*: SAT verbal and math scores were only available in 7 of the 8 institutions. The results for this variable were obtained using only those 7 institutions.

**: High school GPA was only available in 6 of the 8 institutions. The results for this variable are obtained using only those 6 institutions.

IV. Conclusion

The flow of engineering and non-engineering students throughout their undergraduate careers was studied using a very large collection of undergraduate data spanning 8 universities and 13 years. It was found that while engineering in general lost significantly more students to non-engineering disciplines than vice-versa, chemical engineering lost the greatest percentage among the engineering subfields. We also determined that while all other engineering subfields lost the greatest percentage of students to business, chemical engineering saw the highest migration to physical sciences, suggesting that chemical engineering attracts more scientifically inclined students than other engineering subfields. This notion is corroborated by the fact that the highest migration from physical sciences back to engineering occurs in chemical engineering.

To better understand these differences, we categorized both demographic and academic differences among chemical engineering, other engineering, science, and non-science undergraduates. We looked at gender, ethnicity, high school GPA, SAT math scores, SAT verbal scores, time to graduation, cumulative GPA, number of major changes, semesters to graduation, cumulative semester hours and average semester hours. Through careful analysis involving multivariate omnibus, MANOVA and ANOVA tests, we found that chemical engineers differed with statistical significance from other engineers, science majors and non-science majors in all of these measures. Furthermore, chemical engineering came out clearly ahead in all academic performance criteria.

Some of the observed trends between engineering and non-engineering students follow patterns observed by Astin [8]; engineers take longer to graduate as measured by time, semesters, or credit hours. Other observations run counter to Astin's findings; whereas Astin found that majoring in engineering had a negative influence on GPA, our study finds that CHE students have higher GPAs than all other groups. Other studies using SUCCEED's LDB will investigate more closely whether the findings of Astin still have applicability within engineering. We are also interested in understanding the connections between performance in individual courses and overall success within engineering programs, and are currently involved in efforts to expand our database to include specific course data.

The size of the database suggests these differences may be inherent throughout engineering programs in the United States. These findings, of course, lend credence to the commonly held belief that chemical engineering is fundamentally different than other engineering disciplines, let alone sciences and non-sciences. This work contributes to the understanding of the precise nature and extent of this difference.

V. References

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