Exploring Chemistry Success in First-Year Engineering Students

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Abstract

This evidence-based practice paper will explore the success of first-semester engineering students in University Chemistry I at a land grant, public university.

The First-Year Engineering Program (FEP) supports the retention and graduation goals for the College of Engineering (CoE) at University of Arkansas (UofA). Since the implementation of FEP in 2007, approximately 33% of engineering students graduate in 4 years, whereas our 5-year and 6-year graduation rates are around 50%. In the first-year curriculum, the "Big Three": Calculus I, University Physics I and University Chemistry I are the classes that all engineering and computer science majors require and thus are a gateway to success in sophomore level engineering classes. These are also the courses that first-year students most frequently identify as being their hardest class. We suspect that the challenge of the "big three" is not unique to UofA.

For this research, we specifically focus on University Chemistry I. The goal of this research is to look at passing rates of first-semester engineering and computer science students in University Chemistry I and the relation between success in this course and other educational factors. These factors include starting math course, incoming high school GPA, student demographics, enrollment in multiple science courses during the first semester, and future chemistry requirements dependent upon planned engineering major. The data considered in this study spans from 2007 to 2020.

All engineering and computer science eight semester degree plans at UofA indicate a starting math class of Calculus I. Although there are variations to math placement each year, on average, approximately 40% of CoE students begin in Calculus I while 30% begin ahead (in Calculus II or higher), and 30% of CoE students begin one or two math class behind (in Precalculus or College Algebra). Our data showed that students beginning in Calculus I or higher had considerably higher pass rate in chemistry compared to students starting in Precalculus or below. We observed that 3.5 GPA emerged as threshold for success in chemistry. Five ethnicity groups stand out as having pass rates below the overall percentage for chemistry; these populations of students represent 11.3% of the overall student cohort. We also calculated that out of the freshman engineering students who failed Chemistry I on their first fall semester, only 29% continued with engineering in their second fall semester. We did not see a significant relation between the pass-fail rates and instructor of the course or engineering major although the students who continued with majors with additional chemistry requirements passed their first chemistry course at a slightly higher rate. Lastly, one unexpected result we found was that students who were enrolled in "Big Three" tended to do better in Chemistry I than those who were in one science course and Calculus I.

The results of this study will be used by academic advisors and college administrators to determine additional support and programming needed for students identified as less likely to be successful in University Chemistry I.

Introduction

Many of the grand challenges facing the world today including economical clean energy, enhanced virtual reality, improved medicine and health informatics, improved infrastructure, enhanced cybersecurity, and consistent access to clean water will require the innovative solutions of the science and engineering workforce. Government incentives have been created to increase interest in and access to engineering education. However, the Bureau of Labor Statics still predicts that the shortage of engineers in the US will exceed 1.2 million by 2026. In short, we need more engineering graduates to fill these voids which necessitates the need for academic success in the engineering curriculum.

With nation-wide graduation rates for engineering still holding steady around 50%, engineering educators and advisors are seeking ways to improve student retention and graduation. Studies have identified several factors that drive students to leave engineering including classroom climate, self-confidence/self-efficacy, academic preparedness, career interests, race and gender, and academic success (i.e., grades and conceptual knowledge,) [1].

Math has long been considered the major academic "hurdle" in engineering study. In a previous study, we explored the pass and graduation rates of our freshman engineering cohort based on math courses [2]. But, other challenging core requirements in science could also play a major role. In the first-year curriculum at UofA, the "Big Three": Calculus I, University Physics I and University Chemistry I are the classes that all engineering and computer science majors require and thus are a gateway to success in sophomore level engineering classes. These are also the courses that our first-year students most frequently identify as being their hardest class. We suspect that the challenge of the "big three" is not unique to UofA.

Chemistry is viewed as a challenging course for many students because it is often viewed as a content-oriented course that may or may not feel applicable to all engineering disciplines [3]. However, chemistry can serve to bolster academic maturity, because these courses offer opportunities for students to apply math to solve problems, work closely with units and conversions, and develop problem-solving skills [4]. The purpose of this paper was to explore chemistry success in First-Year engineering students and what we can learn about the relationship between chemistry and engineering academic success.

Project Approach

All undergraduate degree programs within the College of Engineering require University Chemistry I (CHEM 1103). This is typically taken during the students' first semester. College of Engineering does not require CHEM 1101L University Chemistry Lab. Students who major in Chemical Engineering, Biological Engineering, and Biomedical Engineering are required to take University Chemistry II, while this second chemistry course is an optional science elective for the other majors. Most of our investigation therefore focuses on University Chemistry I taken by College of Engineering students in their first semester. We dissected how their success varied across math placement, high school GPA, student demographics, science course load, and

chemistry requirements for planned major. The data analyzed in this study was for the students who started as new freshman engineers from 2007 to 2020 at UofA (n=9260).

Research Questions:

Did the Pass-Fail rates and grade distribution in University Chemistry I differ when comparing any of the following variables:

- Starting Math Class?
- High School GPA?
- Student Ethnicity Demographics?
- Science Course Load?
- Planned Engineering Major?

Results and Discussion

CHEM 1103 University Chemistry I at UofA is offered every semester and has a cohort size of 1200-1400 students in fall semesters and 300 – 850 students in spring semesters. These are large classes (200+) that are taught in large auditoriums. In spring 2018 and fall 2018, Chemistry department had a pilot program where they tested whether small class sizes (30 to 40 students) would improve outcomes compared to large class sizes (200+); they did not find a significant difference in student outcomes. Since Fall 2017, Chemistry has been using the flipped classroom format, where students were provided videos on each learning objective to watch before class along with a reading assignment and short online homework assignment. Knowing that most students have not completed the videos, most instructors continued to use class time for lecture. Each student is also required to sign up for Supplemental Instruction (SI) session outside the regular class times. SI offers the opportunity to gather with classmates, discuss ideas, ask questions, and develop strategies for learning. A lab class CHEM 1101L is offered along side CHEM 1103, but because engineering majors take additional science classes with labs they are not required to enroll in CHEM 1101L.

As engineering degree programs worked to reduce the number of credit hours needed and to focus chemistry content on those topics specifically relevant for engineering majors, UofA created a course called Chemistry for Engineers (CHEM 1113). CHEM 1113 was an option for freshman engineering students only in 2012 – 2014. Most students (>85%) took CHEM 1113 instead of CHEM 1103 in these academic years. The data presented in the paper has CHEM 1103 and CHEM 1113 numbers combined and displayed as CHEM 1103. During our study 6,575 students (71% of cohort) enrolled in CHEM 1103 during their first fall semester.

The eight semester degree plans for all majors in the College of Engineering recommend taking CHEM 1103 in the first fall semester. However, college algebra is a pre-requisite for CHEM 1103. Those students who began their first math course in college algebra were required to delay CHEM 1103 until the spring semester. Also, up until Fall 2021, both chemistry and physics were recommended along with Calculus I in the first fall semester. We refer to these courses as the “Big Three”. The distribution of first year students who enrolled in CHEM 1103, the “Big Three, and various math courses are detailed in Table 1 below.

Table 1. Distribution of 9260 freshman engineering students in 2007 – 2020 cohorts. Out of these 9260 students, 6575 took CHEM 1103 during their first fall semester.

First Fall Semester	Total # of Students	% took CHEM 1103*	% in Big Three	% in Algebra	% Precalculus	% Calculus I	% Calculus II and above
2007	378	83%	31%	6%	20%	55%	19%
2008	446	75%	32%	6%	17%	56%	20%
2009	406	63%	30%	9%	22%	50%	17%
2010	539	75%	19%	15%	30%	34%	19%
2011	703	66%	24%	16%	33%	34%	17%
2012	778	71%	21%	19%	31%	30%	20%
2013	688	75%	24%	16%	30%	31%	21%
2014	724	71%	20%	17%	30%	25%	28%
2015	808	73%	21%	14%	30%	29%	26%
2016	759	76%	22%	10%	24%	36%	29%
2017	802	79%	36%	6%	17%	45%	31%
2018	818	71%	30%	8%	17%	43%	31%
2019	715	63%	23%	9%	19%	43%	28%
2020	696	57%	18%	16%	18%	40%	24%

Some students did not feel comfortable enrolling in the "Big Three" in their first fall semester and chose to delay taking one of the sciences until the spring or delaying one of these sciences classes that is perceived as "harder" for an easier science elective (i.e, biology, geology or survey of the universe). From 2007-2020, on average 71% of students enrolled in CHEM 1103 in their first semester. The enrollment percentage dropped in more recent years, where 71% in 2018, 63% in 2019 and 57% in 2020 enrolled in CHEM 1103 in their first fall semester. The percentage of students enrolling in chemistry in the first semester varied by year likely due to pre-requisites, incoming credits for chemistry, and changes in advising. For example, in 2018, out of 818 students, 584 (71%) took CHEM 1103, and 231 did not take a Chemistry class. Out of those 231 students, 64 (28%) students were in College Algebra (ineligible due to math pre-requisite), 32 had AP CHEM credit, and 19 had CHEM dual credit from another college or University. 109 students in Calculus I and above were enrolled in a Physics course. In 2019, out of 715 students, 452 (63%) took CHEM 1103, and 261 did not take a Chemistry class. Out of these 261 students, 66 (25%) students were in College Algebra, 36 had AP CHEM credit, and 14 had CHEM dual credit, (with 5 students that have both AP/dual credit). 142 students in Calculus I and above were enrolled in a Physics course.

Overall Grade Distribution in CHEM 1103

Figure 1 summarizes the overall grade distribution in CHEM 1103 from 2007-2020 for the 6575 freshman engineering students who enrolled in the course during their first fall semester. In this course, D is considered passing so we observed ABCD rates (Pass) and FW rates (Fail). Over the timeframe of this study, the pass rate for CHEM 1103 was 85.1% and the fail rate was 14.9%.

Note that the data shown in Figure 1 excludes grades recorded as No Credit (NC). During covid-impacted semesters, students were given the option to turn failing grades into NC on their transcript so that these courses would not impact their GPA calculations. There were 14 students who chose NC in fall 2020 (0.2% of total).

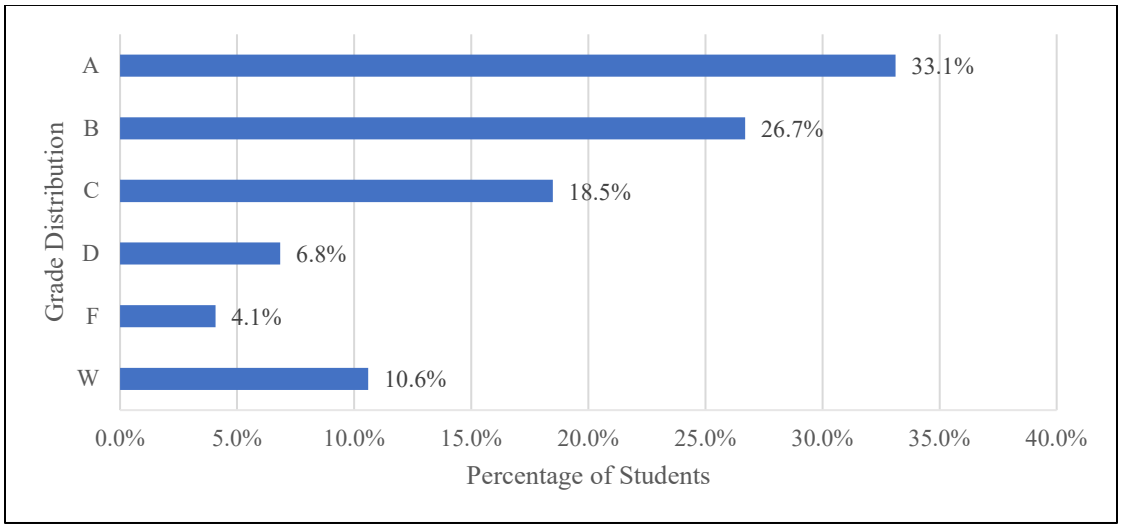

Figure 1. CHEM 1103 grade distribution for 2007-2020 freshman engineering cohort students enrolled in chemistry in their first fall semester (n = 6575).

Chemistry Grade Distribution by Initial Math Class

Despite the feeling that Chemistry is a difficult course, we see a respectable pass rate of 85% for our cohort of students from 2007-2020. Table 2 details the chemistry grade distribution by initial math class group. The math courses in "other" category are Discrete Math, Linear Algebra, and Combinatorics.

Table 2. CHEM 1103 grade distribution by initial math class for freshmen engineering students 2007-2020 cohort who took CHEM 1103 on their first fall semester (n = 6575).

Math Group	A	B	C	D	F	W	Pass rate	Fail Rate	# of Students
Algebra	3%	15%	13%	17%	19%	31%	50%	50%	104
Precalculus	12%	24%	27%	11%	6%	20%	73%	27%	1947
Calculus I	34%	30%	18%	6%	4%	7%	89%	11%	2903
Calculus II	56%	26%	10%	4%	1%	3%	96%	4%	1007
Cal III and Diff Eq	66%	22%	7%	1%	1%	2%	96%	3%	500
Other	71%	17%	4%	1%	0%	7%	93%	7%	72
No Math	40%	29%	12%	5%	0%	14%	86%	14%	42

When you consider the pass rate for students enrolled in Calculus I or higher (on pace or ahead of the eight semester degree plans), the pass rate increases; likely due to the mathematical maturity that comes from advanced math courses and the nature of chemistry problems that relies heavily on mathematical concepts. Students who start in Algebra do poorly in the class at a 50% pass rate. Traditionally, students have been advised to not attempt chemistry until they are in a higher math course; more recently, in Fall 2018, algebra has shifted from being a co-requisite to a pre-requisite.

Chemistry Pass and Fail Rate by Incoming High School GPA

Many studies have shown that high school GPA is a good predictor of collegiate student success [5-7]. As expected, we observed that the higher the high school GPA, the higher the pass rate in Chemistry I. Figure 2 breaks high school GPA into ranges and shows the pass rate (ABCD) and fail rate (FW+ NC during fall 2020) for each range. Students who enter their first college semester with a GPA of 3.5 or higher had a ≥ 83% pass rate in CHEM 1103 on their first fall semester. Therefore, we observed that 3.5 GPA emerged as threshold for success in chemistry. The pass rate drops for those below 3.5 and students were more likely to receive an F or W if their high school GPA was below 3.0.

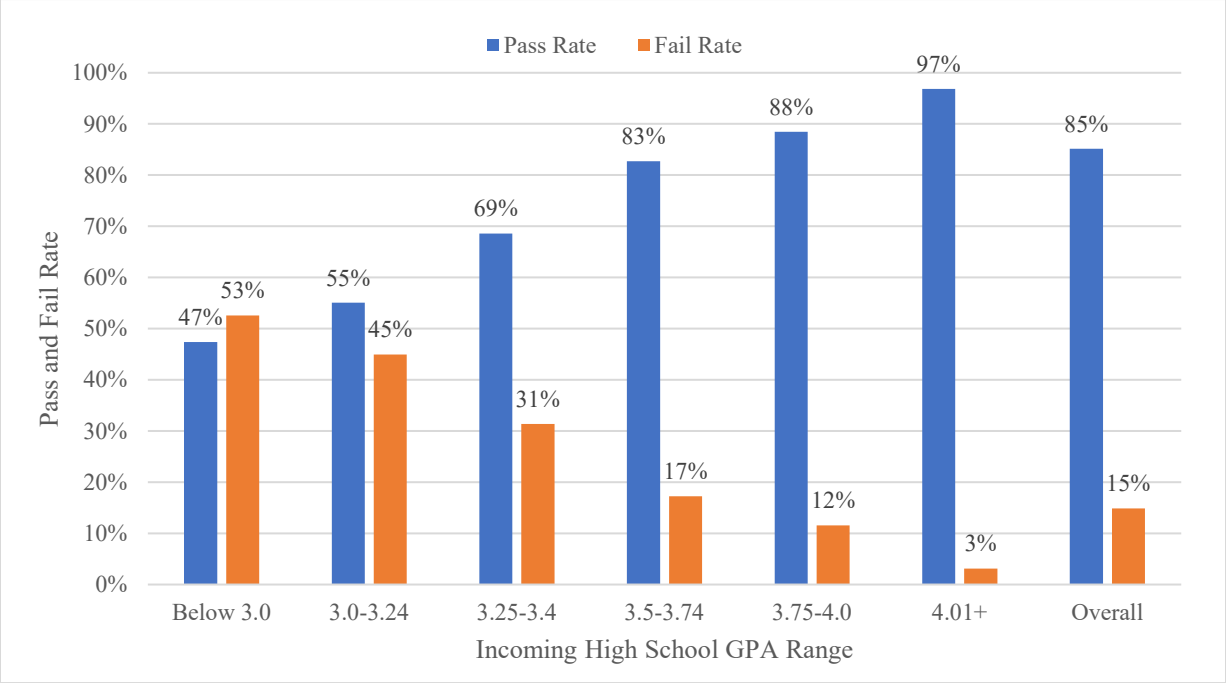

Figure 2. CHEM 1103 grade distribution by High School GPA for 2007-2020 freshman engineering cohort students enrolled in chemistry in their first fall semester (n = 6575).

Chemistry Pass and Fail Rates by Student Ethnicity Demographics

Table 3 and Figure 3 detail the breakdown of pass and fail rates in CHEM 1103 by student identified ethnicity. As previously discussed, the overall pass rate for this course was 85%. When we consider pass rates by ethnicity, five groups stand out as having pass rates below the

overall percentage. Students who identify as African American (74% pass rate), Hispanic (83% pass rate), Hawaiian/Pacific Islander (50% pass rate), Native American (71% pass rate) and Unknown (67% pass rate) had lower pass rates in chemistry. These populations of students represent 11.3% of the overall student cohort.

Table 3. Number of students who identify as each ethnicity group for 2007-2020 freshman engineering cohort students enrolled in chemistry in their first fall semester (n = 6575)

Abbreviation	**Ethnicity**	**# of Students in each ethnicity group who took CHEM 1103 on 1st fall semester**
AA	African American	261
AS	Asian	288
CA	Caucasian	5058
FO	Foreign Other/International	138
HI	Hispanic	480
HW	Hawaiian/Pacific Islander	2
IN	Native American	63
NR	Not Reported	35
TM	Three or More	247
UN	Unknown	3

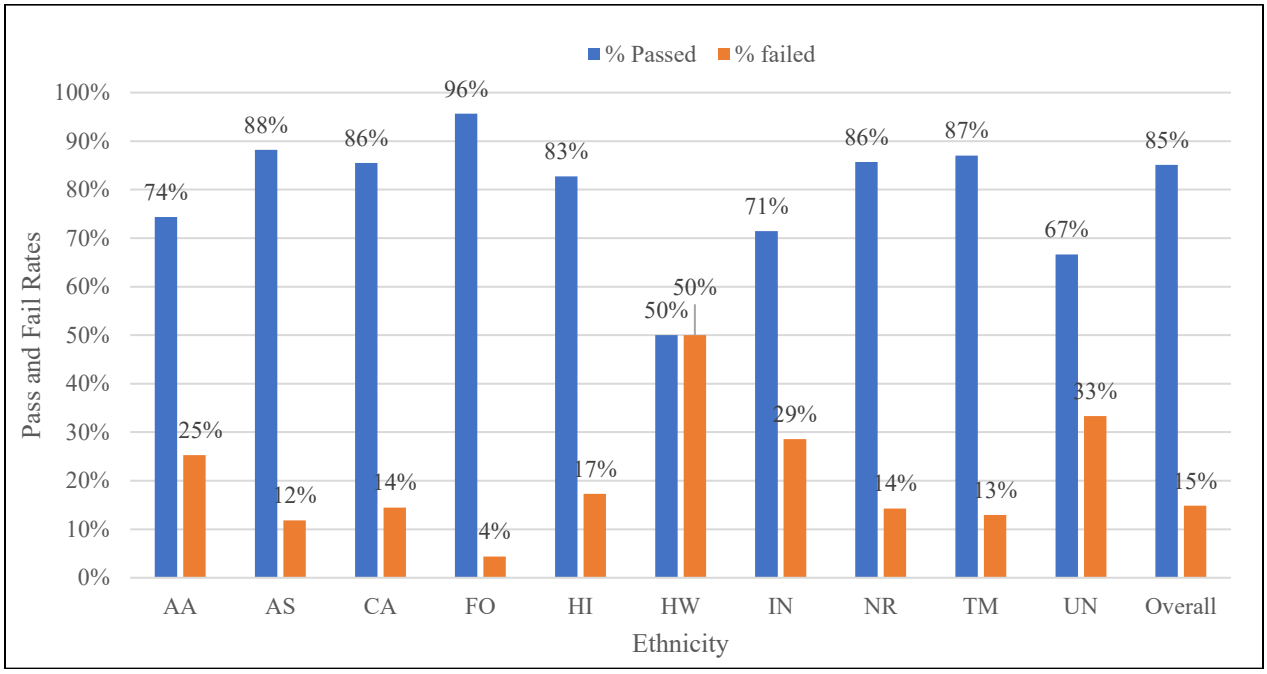

Figure 3. Pass and fail rates for CHEM 1103 distributed by ethnicity groups for 2007-2020 freshman engineering cohort students enrolled in chemistry in their first fall semester (n = 6575).

Chemistry Pass and Fail Rates by Science Course Load

CoE at the University of Arkansas defines the "Big Three" as students enrolled in Calculus I, University Chemistry I and University Physics I (PHYS 2054) in the same semester. The "Big Three" was recommended in the eight semester degree plans for First Year Engineering students from 2007-2021. In 2021, Calculus I became a pre-requisite for Physics I where it had previously been a co-requisite. Figure 4 compares the pass rate in Chemistry I for students who were enrolled in Calculus I, Chemistry I, and Physics I in their first semester with those who only enrolled in Calculus I and Chemistry I and delayed enrolling in Physics I.

The overall pass rate in Chemistry I was higher for those who enrolled in "The Big Three" (89.4%) as compared to those only enrolled in Chemistry I and Calculus I (84.6%). In fact, a higher percentage of students earing As and Bs in Chemistry I were also enrolled in Physics I. The shift occurs for students earning C, D, F and W where a higher percentage of students earning these grades were not enrolled in Physics I in the same semester. While it may seem contrary that students were more successful while enrolled in a more rigorous course load, it is possible that this load pushed the students to work harder all around or that content from the three courses supported each other and pushed students to develop an academic maturity needed for greater success.

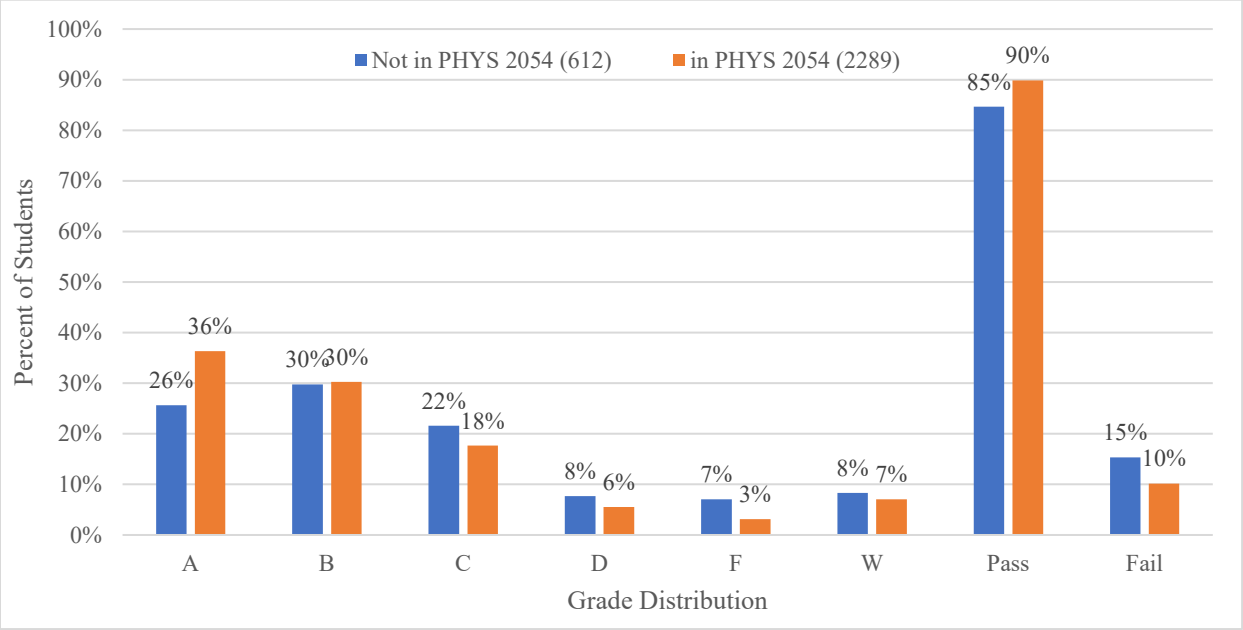

Figure 4. Pass and fail rates for CHEM 1103 distributed by science course load for 2007-2020 cohort. All students represented in the data were enrolled in Calculus I and CHEM 1103 during first fall semester.

Chemistry Pass and Fail Rates by Planned Major

Of the 6,575 freshman engineering students who enrolled in University Chemistry 977 (15%) failed the course from 2007-2020. Of those students, 281 (29%) continued with engineering in the second fall semester, 206 (22%) remained at the University of Arkansas, but changed their major to something outside of the college of engineering, and 490 (50%) did not have a second fall major recorded indicating that they had suspended their enrollment at the University of Arkansas. This breakdown is different for those who passed chemistry in their first fall. Of the 5,598 students (85%) who passed chemistry in their first fall semester, 4,482 (80%) were still engineering majors in their second fall semester, while 647 (12%) remained at the University with a major other than engineering, and 497 (9%) did not have a second fall major (i.e., were no longer at the University). These various paths are mapped in Figure 5.

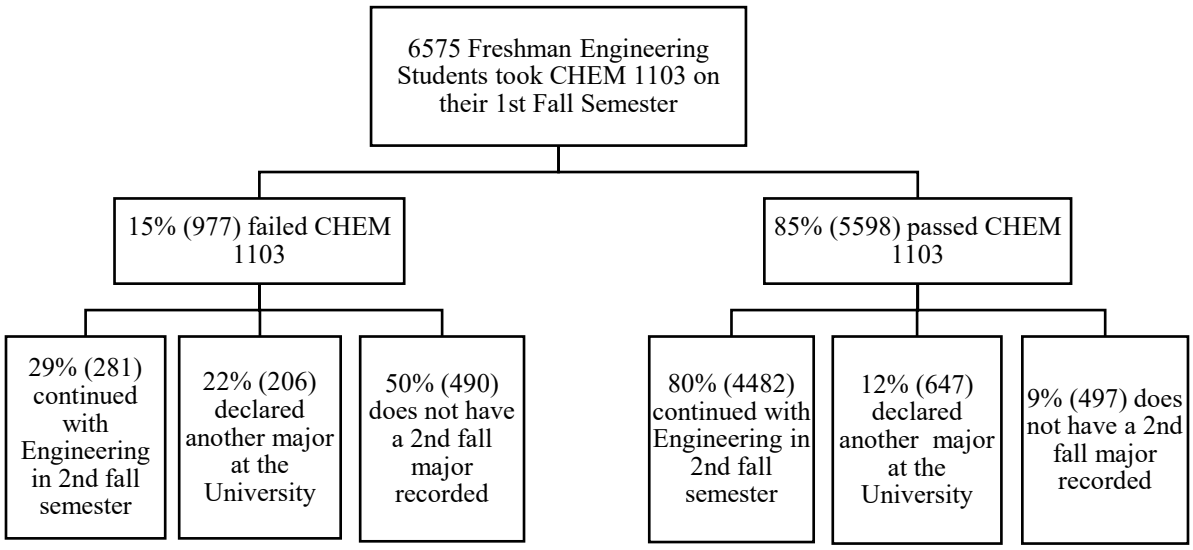

Figure 5. The academic path that students follow after enrolling in University Chemistry (CHEM 1103) during the first semester at the University of Arkansas College of Engineering from 2007-2020.

Focusing in on the students who remained in the College of Engineering (n = 4,763) at the start of the second fall semester, it is interesting to continue to follow the path of majors within the College of Engineering. Table 5 details the Chemistry I grade distribution for each major within the College of Engineering that the students had declared at the start of the second fall semester. Pass rates for Chemistry I were >90% for all College of Engineering majors except for those student pursing a BA in Computer Science (86% pass rate) and those who were still listed as Engineering Freshman (71% pass rate). Students are still listed as Engineering Freshman at the start of their second semester if they have not completed calculus I and or the required Introduction to Engineering two course sequence. The majority of the students in this category begin their math course of study in College Algebra in their first fall semester, and they did not complete calculus I over the summer between first and second years.

University Chemistry II is a required course for students pursuing biological, biomedical and chemical engineering. It is an elective for all other engineering majors. Students who went on to declare biological, biomedical or chemical engineering had a pass rate of ≥ 98%. Those who did not pass withdrew from the course; no Ds or Fs were received by these students. The pass/fail rates and grade distribution for Chemistry I by declared major is summarized in Table 5.

Table 5. CHEM 1103 grade distribution for 2007-2020 cohort of students who took CHEM 1103 during their 1st fall semester and are engineering majors listed below at the beginning of 2nd fall semester.

Engr Major	# of Students	A	B	C	D	F	NC	W	Pass	Fail
Biological	264	53%	31%	11%	3%	0%	0%	2%	**98%**	**2%**
Biomedical	442	55%	32%	10%	2%	0%	0%	2%	**98%**	**2%**
Chemical	461	64%	24%	10%	1%	0%	0%	1%	**99%**	**1%**
Computer Engineering	275	35%	34%	19%	7%	1%	0%	5%	94%	6%
Computer Science BA	22	5%	36%	36%	9%	0%	0%	14%	86%	14%
Computer Science BS	563	37%	31%	20%	5%	1%	0%	6%	93%	7%
Civil	467	38%	33%	19%	5%	0%	0%	4%	96%	4%
Electrical	366	45%	30%	18%	3%	1%	0%	2%	97%	3%
Industrial	501	37%	36%	17%	4%	0%	0%	6%	94%	6%
Mechanical	1040	40%	34%	19%	3%	0%	0%	4%	96%	4%
Engineering Freshman	328	8%	19%	28%	16%	11%	0%	18%	**71%**	**29%**

Chemistry Grade Distribution by Instructor of the Course

Student experience in any class can be influenced by the course instructor. While all University Chemistry I sections have the same common class material, exams and grading methods, the course delivery methods in the classroom vary by instructor. We investigated the grade distribution by course instructor to see if any differences stand out between sections. We also explored any possible differences between CHEM 1103 University Chemistry I and CHEM 1113 Chemistry I for Engineers (only offered 2012-2014). There have been 11 course instructors in the timeframe of our data with various levels of class load. As seen in Table 6 below, 3 of the 11 instructors have interacted with most of the students over the study timeframe.

When examining Figure 6, there are no notable differences in the grade distribution between instructors. It may be worthwhile to note that it appears there was a higher pass rate in Chemistry I, with instructors that had a smaller class size (e.g., instructor 7), but this instructor only taught one semester so it is difficult to draw many conclusions from this data. Instructors 8 and 9 were the only instructors to teach both CHEM 1103 and CHEM 1113. The pass rates in these classes were similar regardless of which chemistry course the students enrolled in.

Table 6. Course load of Chemistry Instructors for 2007-2020 freshman engineering cohort students enrolled in chemistry in their first fall semester.

	CHEM 1103	CHEM 1113	Overall # of Students
Instructor 1	1690		1690
Instructor 2	353		353
Instructor 3	1189		1189
Instructor 4	462		462
Instructor 5	175		175
Instructor 6	63		63
Instructor 7	12		12
Instructor 8	35	158	193
Instructor 9	1138	867	2005
Instructor 10	54		54
Instructor 11		380	380

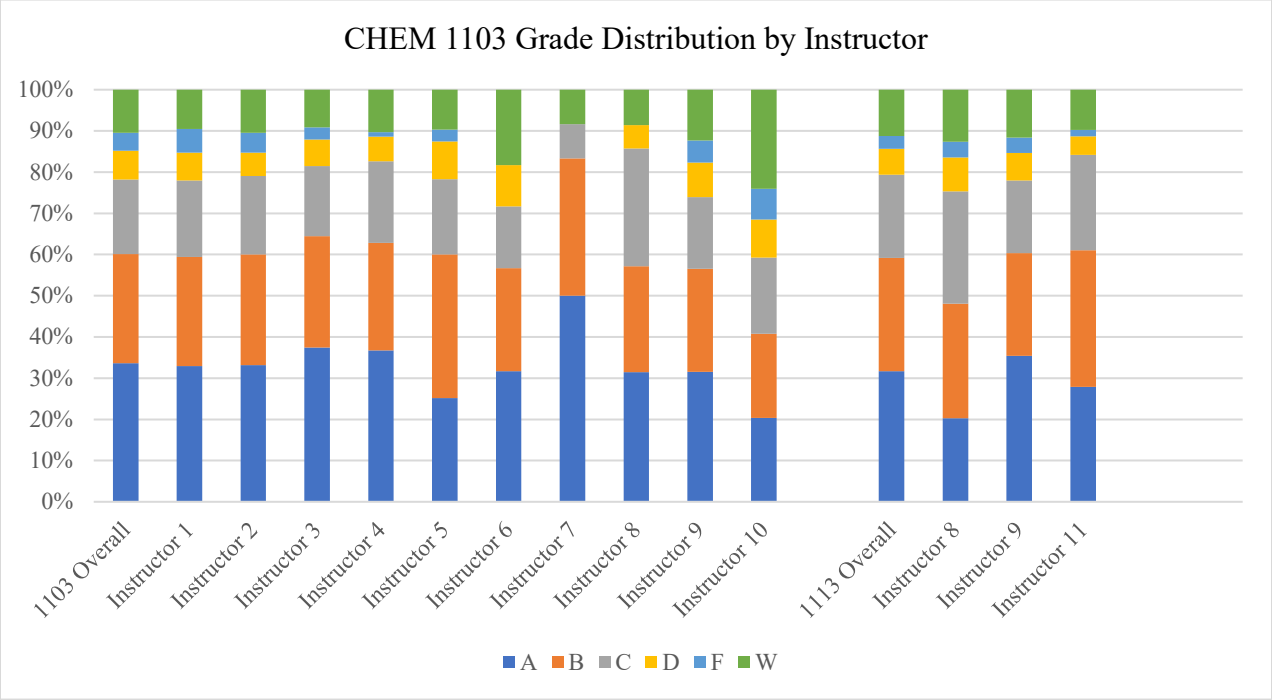

Figure 6. Pass and fail rates for CHEM 1103 and CHEM 1113 distributed by instructor for 2007-2020 freshman engineering cohort students enrolled in chemistry in their first fall semester.

Summary and Conclusions

6,575 freshman engineering students were enrolled in University Chemistry I during their first fall semesters from 2007 - 2020. Out of this group, 85% (5598) passed the course, while 977 (15%) failed. Of those 977 students who failed, only 281 (29%) continued with engineering in the second fall semester, 206 (22%) remained at the University of Arkansas but changed their major to something outside of the college of engineering, and 490 (50%) did not have a second fall major recorded indicating that they had suspended their enrollment at the University. There

can be many factors that affect the student's decision to discontinue engineering; we cannot single out Chemistry I grades as the main reason, but we note the correlation between failing Chemistry I during first semester and deviation from engineering majors.

Our results also showed that initial math class is notable in students' success rate. Although students were advised against this, small group of students who started in College Algebra had a 50% pass rate in CHEM 1103. Those who started in Calculus I or higher had pass rates ≥ 89%. This fact led to restructuring in Fall 2018. Algebra was shifted from a co-requisite to a pre-requisite course. Thus, allowing time for students to build a better foundation in their mathematical and critical thinking skills.

As suspected, we observed that high school GPA is a good indicator for success in Chemistry I. A student with a high school GPA of 3.5 or higher had a ≥ 83% pass rate in CHEM 1103 on their first fall semester.

Five different ethnicity groups that represent 11.3% of the overall student cohort studied had pass rates below the overall percentage: students who identify as African American (74% pass rate), Hispanic (83% pass rate), Hawaiian/Pacific Islander (50% pass rate), Native American (71% pass rate) and Unknown (67% pass rate).

There was no significant change in grade distribution across instructor. Chemistry I is a service level course; hence, it can have large classroom sizes. It may be worthwhile to note that it appears there was a better pass rate in Chemistry I, with instructors that had a smaller class size. However, with such a small sample size this would be difficult to analyze.

Those enrolled in "The Big Three" had better success rates than those enrolled in Chemistry I and Calculus I and not Physics I. Physics I is considered a difficult course with a heavy workload including long lab hours; therefore, this result may seem unexpected. But, it is possible that "The Big Three" pushed the students to work harder and to develop academic maturity or that content from the three courses supported each other. Additional analysis would be needed.

The results of this study will help us with the upcoming summer and fall advising meetings. Advisors can consider the high school GPA and initial math placement while helping students form their schedule. Students with low GPAs or lower math placements can be discouraged from taking heavier course loads on their fall semester in order to focus on their chemistry and math courses. Also, the academic coaches can be intentional about reaching out to students in this group to provide them extra encouragement to use the available resources.

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