Longitudinal Effects of the Foundation Coalition Curriculum on Chemical and Petroleum Engineering Student Performance

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Abstract

This Complete Research explores the longitudinal effects of the Foundation Coalition (FC) curriculum on chemical and petroleum engineering student graduation outcomes: retention, time-to-graduation, and cumulative GPA. In 1993, a large southwest public university joined the FC, a 10-year multi-university NSF initiative to improve first-year engineering (FYE) education. After pilot classes were developed, in 1998 the FC curriculum was implemented college-wide. In 2003, the university adopted a track system with the FYE foundational courses separated into three tracks: Track A (aerospace, agricultural, biomedical, civil, industrial, mechanical, and nuclear engineering), Track B (computer and electrical engineering), and Track C (chemical and petroleum engineering). Track A was primarily project-based and used Mindstorms, Legos, magnetic balls, and beams to build structures. Track B focused on circuit design and computer programming. Only Track C maintained the FC curriculum until 2013. The target population of this study is first-time-in-college (FTIC) chemical or petroleum engineering students who started in summer or fall during the 2005 to 2007 school year and took Track A (339 students) or Track C (256 students). There was no statistically significant difference in retention. Although Track C students graduated in engineering 0.18 semesters quicker than Track A students, the differences were not statistically significant. However, there was a statistically significant difference in the cumulative GPAs when they graduated in engineering: Track C students' average cumulative GPA (3.27) was significantly higher than Track A students (3.16).

I. Introduction

A. Background

In 1993, a large southwest public university joined the Foundation Coalition (FC), a 10-year multi-university NSF initiative to improve first-year engineering (FYE) education (Clark, Froyd, Merton, & Richardson, 2003; Cordes, Evans, Frair, & Froyd, 1999; Fournier-Bonilla, Watson, & Malavé, 2000; Holtzapple, Toback, & Holtzapple, 2014). Pilot classes were developed, refined, and evaluated for years (Al-Holou et al., 1999; Barrow et al., 1995). Finally, in 1998, the FC curriculum for two engineering foundational courses for one school year was scaled up and implemented as part of the FYE common curriculum at the large southwest public university (Fournier-Bonilla, Watson, & Malavé, 2000; Fournier-Bonilla, Watson, Malavé, & Froyd, 2001). The courses were team-taught by two instructors, one drawn from the engineering departments and one from the graphics faculty.

Later, a "barter" system was developed where each department was obligated to assign faculty to the course. In some cases, departments took this obligation seriously and assigned dedicated faculty. In other cases, there was minimal commitment; sometimes, graduate students were assigned to teach the class. The course was pretty broad and had the following issues: (a) some faculty did not feel comfortable teaching material outside their major; and (b) some faculty felt it was a waste of time to teach topics that did not directly impact their students.

In 2003, the course was separated into three tracks: (a) **Track A** for aerospace, agricultural, biomedical, civil, industrial, mechanical, and nuclear engineering majors, (b) **Track B** for computer and electrical engineering majors, and (c) **Track C** for chemical and petroleum engineering majors. Track A was primarily project-based and used Mindstorms, Legos, magnetic balls, and beams to build structures. This track benefited from additional NSF funding designed to improve the FYE education (Froyd & Ohland, 2005). Track B focused on circuit design and computer programming. Only Track C maintained the FC curriculum and continued to refine it. For ten years (2003 to 2013), the FYE students at the university were taught in three tracks (Holtzapple, Toback, & Holtzapple, 2014).

B. The Foundation Coalition Curriculum

From 1993 to 2004 when the National Science Foundation (NSF) funded the Foundation Coalition (FC) to reform and improve the education of freshmen engineers, the FC curriculum included the following four themes: integrated curriculum, active/cooperative learning, technology-enabled learning, and continuous improvement (Morgan & Bolton, 1998; Froyd & Ohland, 2005).

Integrated curriculum. The FC curriculum is designed to integrate with both the freshman and upperclassman years. To support the freshman year, the curriculum reinforces physics, chemistry, and mathematics. To support the upperclassman years, the curriculum includes foundational topics, such as thermodynamics, rate processes (e.g., fluids, heat transfer, and electricity), and "engineering accounting," which is discussed later. A detailed description of the two engineering foundational course content is provided in Table 1.

Active/cooperative learning. Students are organized into teams of three to four. Lectures are interspersed with frequent group activities, such as calculating the answer to a problem, discussing various options to arrive at a consensus answer, brainstorming, and working on projects.

Technology-enabled learning. In the classroom, students have their own computer equipped with standard Office software (e.g., Word, Excel) as well as specialized engineering software (e.g., AutoCAD, Inventor). The computers are connected to the internet so students can access the web.

Continuous improvement. The FC course is constantly evaluated to update the content and to improve content delivery.

In addition to the above themes, the FC at the university included the following: (a) clustering of students into "learning communities" who took common courses (math, engineering, science); (b) using student teams both inside and outside the classroom; (c) industry involvement in the classroom; (d) undergraduate peer teachers; and (e) faculty team teaching.

Table 1. *Engineering Foundational Course Curriculum*

First Semester			Second Semester		
Topic	Hrs.	Example Content	**Topic**	Hrs.	Example Content
Introduction			**Introduction**		
Course overview	1.5	Grading, homework format, contact information, course philosophy	Course overview	2	Grading, homework format, contact information, course philosophy
Engr. profession	0.5	Technology team, engr. disciplines, engr. functions, ABET	**Computer Tools**		
Teaming	1	Team roles, Code of Cooperation	Visual Basic	4	Functions, subroutines, naming variables, precedence of arithmetic operators, integers, reals, selection structures, repetition structures, arrays, Boolean operations
Time management	1	Goal setting, scheduling, health, study environment, learning	**Rate Processes**	4	Rate, flux, driving force, heat, electricity, fluid flow, diffusion, resistance, series/parallel resistors
Ethics	2	Professionalism, registered engineer, canons, ethical theory	**Engineering Accounting**		
Problem solving	2	Techniques, decomposition, process, constraints, algorithms, flow charts	Basic concepts	2	Defining a system, open/closed, systems, intensive/extensive quantities, state/path quantities, Universal Accounting Equation, conservation, steady state
Engineering Science			Mass	2	Batch/continuous processes, independent equations, matrices
Newton’s laws	2	Newton’s laws, equations of linear motion	Charge	2	Positive/negative charge, Kirchhoff’s Current Law, batteries, simple circuits, equivalent resistance
Units	3	Unit systems, coherent units, dimensional analysis, unit conversion	Linear momentum	2	Forces, changing momentum by changing mass, revisit Newton’s laws
Thermo-dynamics	4	Pressure, temperature, energy, heat, work, enthalpy, ideal gas, First law, Second law, heat capacity, phase diagrams, reversibility	Angular momentum	2	Equations of angular motion, centripetal/centrifugal forces, moment of inertia, torque, particles/bodies
Mathematics					
Numbers	0.5	Significant digits, proportionality, error, precision, accuracy	Energy	4	State/path energy, heat/work, shaft work, electrical work, light, lasers, blackbody radiation, kinetic/ potential/internal energy, sensible/ latent heat, closed/open systems, sequential energy conversion
Graphical analysis	2	Rectilinear, semi-log, log-log, interpolation, linear regression, tables			
Statistics	2	Mean, median, mode, standard deviation, histograms, normal distributions, *Z*-tables	Entropy	2	Natural/unnatural processes, reversible/irreversible processes, cycles, Second law
Computer Tools					
Excel	5	Spreadsheets, graphing, solver, statistical functions, graphing, numerical integration	Money	2	Interest, compounding, present worth, discount, inflation/ deflation, annuities, installment loans
Graphics	18	Sketching, lettering, orthographics, pictorials, AutoCAD, dimensions, threads, scaling, sections	**Graphics**	12	Parametric modeling, secondary features, drawings, assemblies, special views
Projects			**Projects**		
Industry Case Study	2		Industry Case Study	2	
Team Project	4	Air-powered car	Team Project	4	Water rocket

Note. Hrs. = Hours

C. Engineering Accounting

Engineering accounting is the most important concept taught in the second semester of the FC curriculum. It is a unifying framework that applies to all engineering disciplines; in fact, engineering disciplines can be distinguished by what they count (Table 2). Here, engineering accounting can only be applied to extensive quantities (e.g., mass, volume, charge, momentum), which depend upon scale. Engineering accounting cannot be applied to intensive quantities (e.g., temperature, pressure, concentration, voltage), which do not depend upon scale. If all engineers are taught the engineering accounting framework, it is much easier for them to work on interdisciplinary projects because they have a common language.

Table 2. *Engineering Disciplines Defined by What They Count*

Engineering Discipline	Mass	Charge	Linear momentum	Angular momentum	Energy	Entropy	Money
Aerospace	X	X	X	X	X	X	X
Agricultural	X	X	X	X	X	X	X
Biomedical	X	X	X	X	X	X	X
Chemical	X	X	X	X	X	X	X
Civil	X		X	X			X
Computer		X			X		X
Electrical		X			X		X
Industrial	X	X	X	X	X		X
Mechanical	X	X	X	X	X	X	X
Nuclear	X	X	X	X	X	X	X

As an integrated curriculum, the FC used engineering accounting to provide the following benefits for students: (a) reinforce student learning, (b) broaden understanding, (c) provide a learning framework, (d) match engineering practice, (e) link disciplines, (f) improve visualization, (g) increase retention, (h) smooth transitions between subjects, (i) establish relevance to engineering career, (j) decrease compartmentalization, (k) connect with learning preferences, (l) avoid haphazard presentation, (m) develop teaming, and (n) improve faculty. Several studies strongly suggested that the Foundation Coalition benefitted all engineering students and hence is suitable for the common curriculum (Fournier-Bonilla, Watson, & Malavé, 2000); however, most studies of the FC curriculum explored the short-term effects rather than long-term effects on student performance.

D. Purpose of the Study

Track A is primarily a problem/project-based learning (PBL) curriculum. In contrast, Track C employs the Foundation Coalition (FC) and is primarily an engineering science-based learning (SBL) curriculum. This study explores the longitudinal impact of PBL vs. SBL curriculum on chemical and petroleum engineering students. To accomplish this, the performance of chemical and petroleum engineering students who took Track C was compared to other chemical and petroleum engineering students who took Track A. The following research question guided this study: Beyond their first year, what are the longitudinal effects of the FC curriculum on chemical and petroleum engineering student performance in terms of (a) graduation status in engineering, (b) time-to-graduation, and (c) cumulative GPA?

II. Method

A. Setting

During each of the 2005 to 2007 school years at the large southwest public university, the first-year engineering foundation courses consisted of about 60 sections. Three sections of approximately 30 students each were taught in a single classroom, which resulted in a class of less than 100 students. The classroom contained a "problem solving" faculty member drawn from the engineering departments and a graphics faculty member. The problem-solving faculty taught within their track whereas graphics faculty taught across tracks. For example, chemical engineering professors only taught Track C whereas graphics faculty taught either Tracks A or C. During the 2005 to 2007 school years, chemical and petroleum engineering students selected either Track A or Track C at the time of the course registration. Ideally, these students would select Track C, which was designed for their major. However, in many cases, students would select Track A for the following reasons: (a) there was a schedule conflict, (b) Track C was full, or (c) they wanted to change their major.

B. Participants

The target population of this study was first-time-in-college (FTIC) chemical or petroleum engineering students who started their first semester in summer or fall of 2005, 2006, and 2007 at a large southwest public university and attempted to take the first semester engineering foundational course in their first fall semester. The population of 595 newly admitted students included 372 chemical engineering and 223 petroleum engineering majors who took Track A or Track C (FC curriculum)[*]. Table 3 shows their demographic characteristics in terms of gender, residence, race/ethnicity, and curriculum track by major.

C. Data Analyses

The participants' academic activities at the university were tracked in fall 2016[†] (i.e., fall 2005–fall 2016) through the data retrieved from the university archive. According to the data, spring 2016 was the semester that showed participants' last academic activities, like graduation from the university. We defined student success in engineering when students graduated in engineering regardless of their entry major. Therefore, participants' graduation status in engineering, time-to-graduation in engineering, and cumulative GPAs were utilized for outcome variables as three indicators of student success in engineering. Here, students' graduation status was categorized into one of three groups: (a) graduation in engineering, (b) graduation in non-engineering, and (c) no graduation. For this quasi-experimental study, Track A students served as a control group and Track C students served as a treatment group for data analyses to explore the impact of FC curriculum (Track C) on student success in engineering.

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[*] Students' data from three faculty members of Track C, who modified the FC curriculum, were excluded, which resulted in more numbers of students in Track A than Track C for both chemical and petroleum engineering majors.
[†] The counting of the semesters was based on the institutional definition in which the summer semesters were counted as fall semesters, so two semesters (i.e., fall and spring) were counted for each school year.

To answer research questions, descriptive statistics were used to identify trends in the data. Then, inferential statistics – such as chi-square tests, independent *t*-tests, and two-way analysis of variances (ANOVAs) – were applied to check statistically significant differences between two groups and among subgroups at the alpha level of .05. All assumptions for inferential statistics (e.g., independent observation, normality, and homogeneity of variance) were checked before the analyses (Field, 2009).

Table 3. *Demographic Characteristics of the Participants*

	Total		Chemical		Petroleum	
Category	*N*	%	*n*	%	*n*	%
Gender						
Female	165	27.7	120	32.3	45	20.2
Male	430	72.3	252	67.7	178	79.8
Residence						
Domestic	576	96.8	365	98.1	211	94.6
International	19	3.2	7	1.9	12	5.4
Race/Ethnicity[a]						
Hispanic	66	10.1	47	12.6	19	8.5
American Indian or Alaska Native	2	0.3	2	0.6	0	0.0
Asian	28	4.7	18	4.8	10	4.5
Black	10	1.7	6	1.6	4	1.8
Native Hawaiian or other Pacific Islander	1	0.2	0	0.0	1	0.4
White	464	78.0	288	77.4	176	78.9
Multi-racial	5	8.4	3	0.8	2	0.9
Engineering Foundational Course Track						
A (Traditional curriculum)	339	57.0	212	57.0	127	57.0
C (FC curriculum)	256	43.0	160	43.0	96	43.0
Total	595	100.0	372	100.0	223	100.0

Note. [a]Race/Ethnicity was categorized for domestic students only and percentages were calculated based on the total number of domestic students**.**

III. Results

A. Graduation Status in Engineering

Figure 1 shows percentages of chemical and petroleum engineering students' graduation status by track. When students who graduated in non-engineering or did not graduate from the university were grouped together, the results of Pearson's chi-square tests showed that there were no significant associations of graduation status with track for each engineering program: $\chi^2(1) = 0.03$, $p = .865$ for chemical engineering majors and $\chi^2(1) = 0.34$, $p = .562$ for petroleum engineering majors.

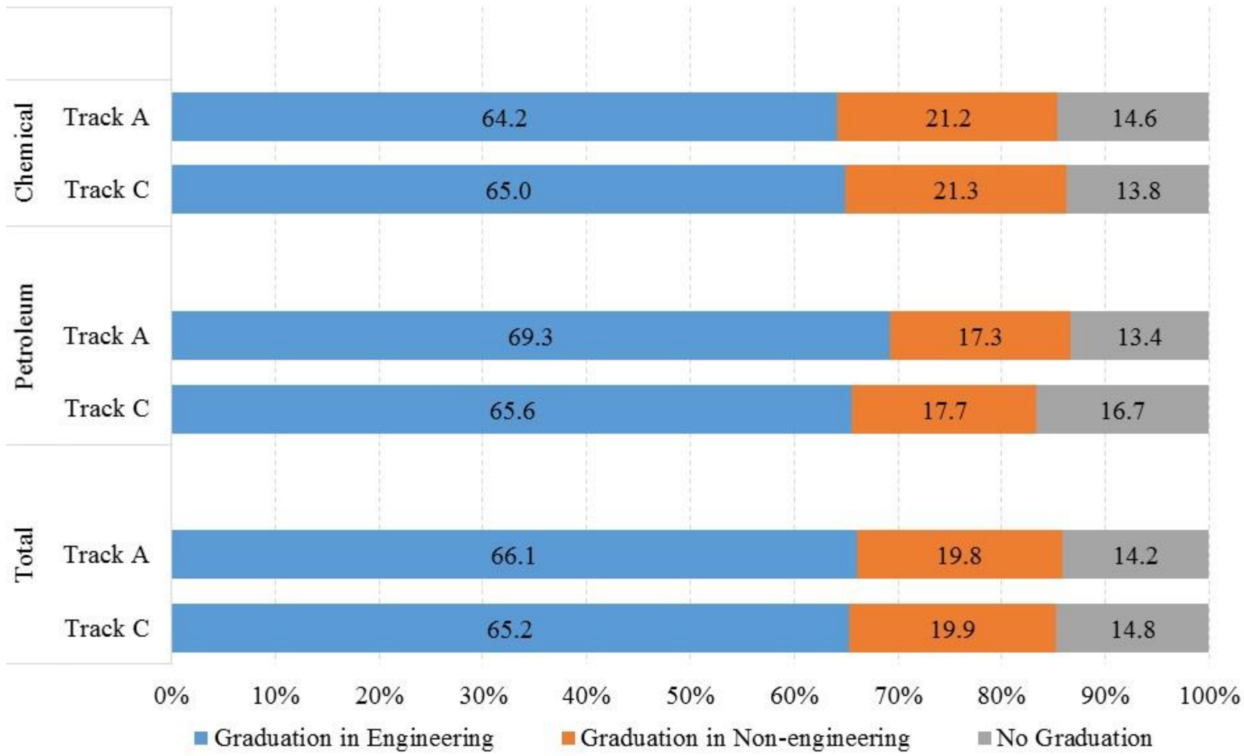

Figure 1. Graduation status of chemical and petroleum engineering students by track.

B. Time-to-Graduation in Engineering

A two-way analysis of variance (ANOVA) showed that there was a significant main effect of major on the participants' time-to-graduation in engineering: $F(1, 387) = 4.8$, $p = .029$, Partial $\eta^2 = 0.012$. However, the effect of track on the participants' time-to-graduation in engineering was not significant with $F(1, 387) = 2.8$, $p = .094$, Partial $\eta^2 = 0.007$. In addition, there was no significant interaction effect between track and major with $F(1, 387) = 1.1$, $p = .285$, Partial $\eta^2 = 0.003$.

The above results imply that the average time-to-graduation in engineering significantly differs only by major, but not by track. In detail, even though average time-to-graduation of Track C students ($n = 167$, $M = 8.98$, $SD = 1.28$) was slightly shorter than Track A students ($n = 224$, $M = 9.16$, $SD = 1.19$), the difference of 0.18 semesters was not statistically significant. However, chemical engineering students' average time-to-graduation ($n = 240$, $M = 9.18$, $SD = 1.28$) was longer than petroleum engineering students ($n = 151$, $M = 8.92$, $SD = 1.13$), the difference of 0.26 semesters was statistically significant with $t(389) = 2.03$, $p = .043$.

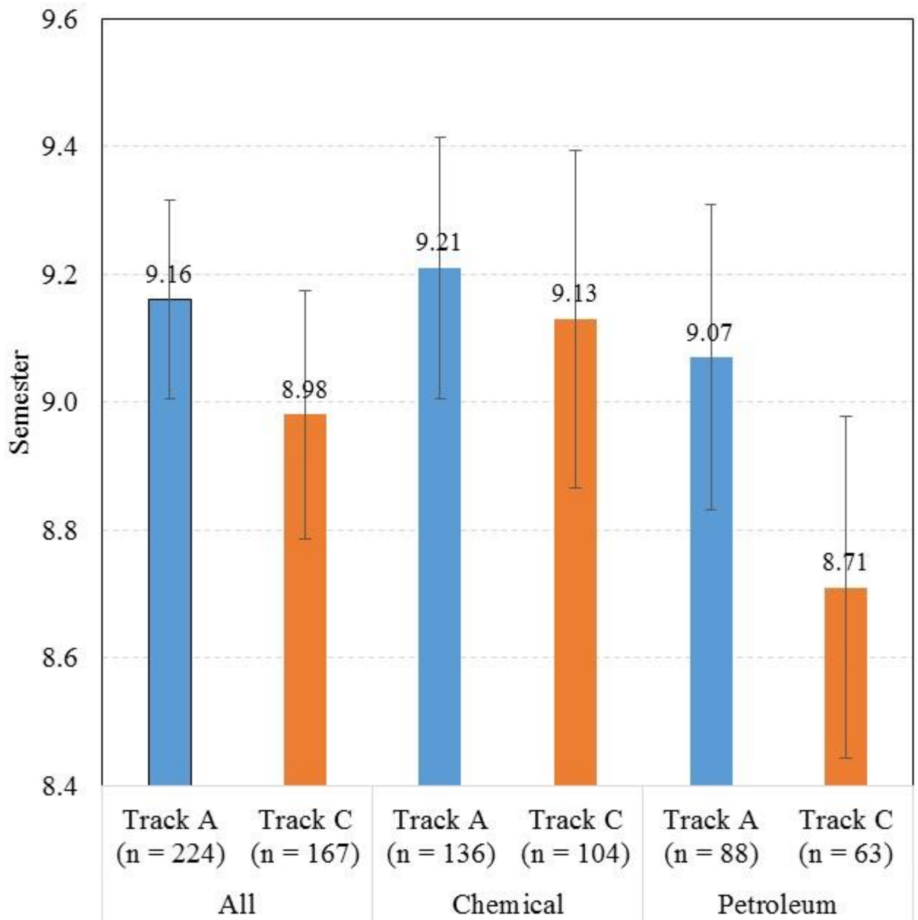

Figure 2. Average time-to-graduation in engineering by major and track (Error bars in 95% confidence intervals)

C. Cumulative GPA by the Time of Graduation in Engineering

A two-way analysis of variance (ANOVA) revealed that there were two significant main effects of track and major each on cumulative GPAs of the participants when they graduated in engineering: $F(1, 387) = 4.4$, $p = .036$, Partial $\eta^2 = .011$ for track and $F(1, 387) = 9.7$, $p = .002$, Partial $\eta^2 = 0.024$ for major. However, there was no significant interaction effect between track and major with $F(1, 387) = 1.3$, $p = .254$, Partial $\eta^2 = 0.0003$. In detail, average cumulative GPA of Track C students ($n = 167$, $M = 3.27$, $SD = 0.46$) was significantly higher than Track A students ($n = 224$, $M = 3.16$, $SD = 0.46$) with 0.11 point difference, $t(398) = 2.47$, $p = .014$. Furthermore, chemical engineering students' average cumulative GPA ($n = 240$, $M = 3.28$, $SD = 0.46$) was significantly higher than petroleum engineering students ($n = 151$, $M = 3.12$, $SD = 0.46$) with 0.16 point difference, $t(389) = 2.99$, $p = .003$. No interaction effect indicates that Track C students tended to have a higher cumulative GPA than Track A students regardless of their major. Similarly, chemical engineering students tended to have a higher cumulative GPA than petroleum engineering students regardless of their track. Figure 3 delineates the average cumulative GPAs by track and major.

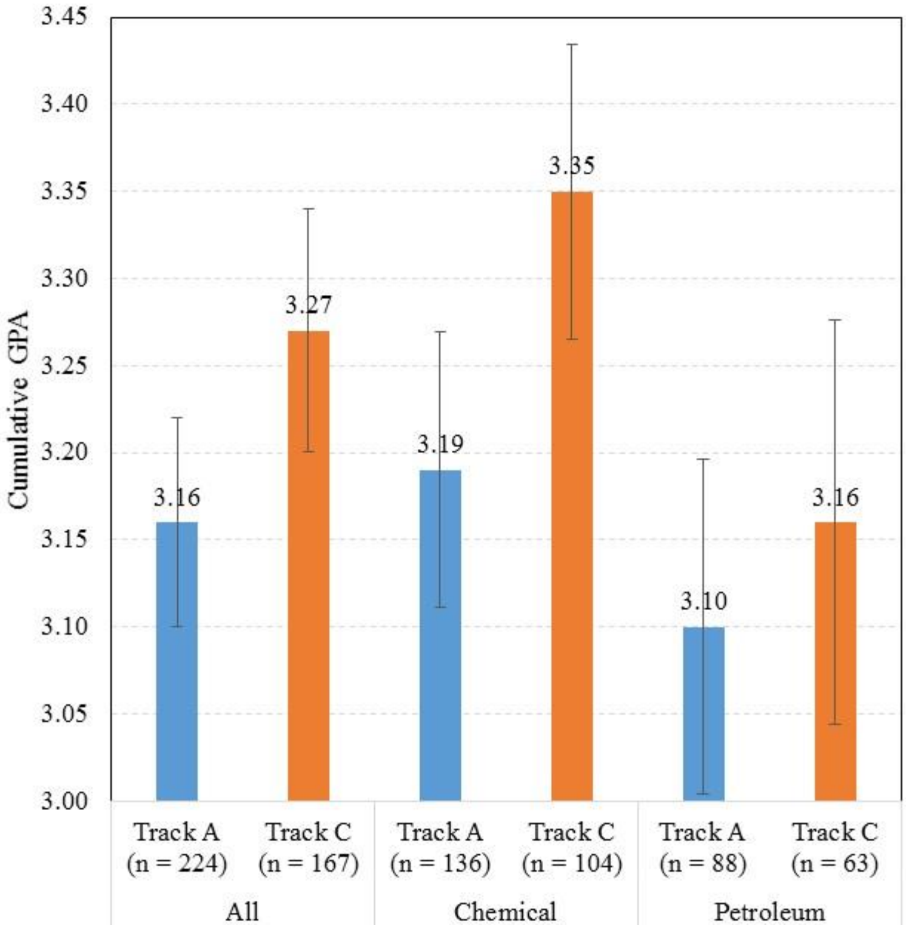

Figure 3. Average cumulative GPAs of participants who graduated in engineering by track and major (Error bars in 95% confidence intervals)

IV. Discussion

Regarding graduation status in engineering, the effect of the FC curriculum on chemical and petroleum engineering students was not significant because there was no significant difference between Tracks A and C.

Regarding time-to-graduation in engineering, Track C students graduated 0.18 semesters quicker than Track A students; however, the differences were not statistically significant. Chemical engineering students' average time-to-graduation (9.18 semesters) was significantly longer than petroleum engineering students (8.92 semesters) regardless of track.

Regarding average cumulative GPAs upon graduation in engineering, Track C students (3.27) were significantly higher than Track A students (3.16). Furthermore, chemical engineering students (3.26) was significantly higher than petroleum engineering students (3.12). In detail, for chemical engineering students, Track C (3.35) was 0.16 higher than Track A (3.19). For petroleum engineering students, Track C (3.16) was 0.06 higher than Track A (3.10).

Although chemical engineering students tended to have higher cumulative GPA than petroleum engineering students, chemical engineering students took longer to graduate than petroleum engineering students. The FC curriculum had no statistically significant impact on students graduating in engineering and time-to-graduation in engineering; however, there was statistically significant impact on cumulative GPA. Track C students showed higher cumulative GPA than Track A students. The effect of the FC curriculum on cumulative GPA was more apparent for chemical engineering students than petroleum engineering students.

One possible explanation for the greater impact of Track C on chemical engineers is their curriculum has a greater component of engineering science as opposed to engineering practice. The Foundation Coalition is designed to emphasize the fundamentals of engineering science rather than engineering practice, and hence is likely to benefit a curriculum with a heavier emphasis on engineering science.

A. Limitation of the Study and Direction for Future Research

In this study, we only explored one-semester effects of the FC curriculum on the participants' performance in engineering. Because the FC curriculum was designed for two semesters, there is a need to explore the full academic year effects of the FC curriculum on student performance. Adding this condition will reduce the sample size because not all students who passed the first-semester engineering foundational course registered for the second-semester course. However, this approach will reveal the full extent of the FC curriculum effects on engineering students' performance.

Although we compared performance between chemical and petroleum engineering students, we acknowledge that each engineering program has a different curriclum and different faculty with their own grading standards; thus, the differences in student performance by major is expected. In addition, in this study, we did not incorporate possible impacts of different instructional strategies by instructors across years because of the limited sample size.

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