International Journal of Engineering Education Vol. 37, No. 6, pp. 1683–1699, 2021
Printed in Great Britain

0949-149X/91 $3.00+0.00

Impact of the First-Year Foundation Coalition Curriculum on Graduation Outcomes of Chemical and Petroleum Engineering Students*

SO YOON YOON
Department of Engineering Education, College of Engineering and Applied Science, University of Cincinnati, Cincinnati, OH 45221, USA. E-mail: yoons5@ucmail.uc.edu

MARK T. HOLTZAPPLE**
Artie McFerrin Department of Chemical Engineering, Texas A&M University, College Station, TX 77843-3122, USA.
E-mail: m-holtzapple@tamu.edu

In 1993, a Southwestern public university in the United States was a founding member of the Foundation Coalition (FC), a 10-year multi-university NSF initiative to improve first- and second-year engineering education. In 1998, the FC curriculum was employed universally; however, in 2003, the engineering college fragmented the first-year curriculum: Track A (project-based learning), Track B (computer and electrical engineering), and Track C (FC concepts in chemical and petroleum engineering). Using the logic model for the Theory of Change, this study explored the longitudinal effects of the Tracks A and C on chemical and petroleum engineering student graduation outcomes: graduation in engineering, time-to-graduation, and cumulative GPA. Participants were 1,022 students who started in chemical or petroleum engineering and enrolled in Tracks A or C from 2003–2007. The graduation outcomes of these students were completed by fall 2016 and were compared using descriptive and inferential statistics. Within a major, tracks had no significant effect on time-to-graduation. However, Track A petroleum engineering students showed improved graduation rates in engineering and Track C chemical engineering students had significantly higher cumulative GPAs. When particular student backgrounds and their first-semester course grade were controlled, Track C students showed significantly reduced time-to-graduation and increased cumulative GPA. This study shows that a first-year engineering curriculum can dramatically impact student outcomes upon graduation.

Keywords: first-year engineering; chemical engineering; petroleum engineering; graduation outcomes; Theory of Change

1. Introduction

In the history of engineering education, there have been numerous initiatives to improve the first-year engineering (FYE) curriculum [1–4]. Most studies were based on funding periods and explored short-term effects of the innovation on student performance; thus, there is a lack of longitudinal studies that explore the long-term effects of FYE innovations [5]. Using the logic model for the Theory of Change [6–10], this study employs a retrospective approach to explore both short- and long-term effects of one of the initiatives for FYE students, which started almost 25 years ago, but continued for more than 20 years at a large Southwestern public university in the United States.

1.1 Background

In 1993, a large Southwestern public university was a founding member of the Foundation Coalition (FC), a 10-year multi-university NSF initiative to improve first- and second-year engineering education [2, 11–14]. For four years, pilot FYE classes were developed, refined, and evaluated [1, 15]. Finally, in 1998, the two-semester FC curriculum was scaled up and implemented universally as part of the FYE common curriculum in the College of Engineering [2, 16]. The FYE FC courses – which were integrated with chemistry, physics, and mathematics – were team-taught by two instructors, one drawn from engineering departments and one from the graphics department. Additional core features of FC included active/cooperative learning, technology-enabled learning, and continuous improvement.

The FC course was very 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. For example, civil engineering faculty complained that their students do not take a thermodynamics course, so there was no need to learn thermodynamics in their first year.

In 2003, the FYE curriculum was fragmented into three tracks: (a) Track A for aerospace, agricultural, biomedical, civil, industrial, mechanical,

** Corresponding author.

* Accepted 16 July 2021.

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 a *project-based learning* (PBL) curriculum and used Mindstorms, Legos, magnetic balls, and beams to build structures. This track benefited from additional NSF funding designed to improve the FYE education [17]. Track A is close to the current traditional curriculum for the vast majority of FYE programs. Track B focused on electrical circuits and computer programming. In contrast, only Track C maintained topics from the FC curriculum, which were designed to integrate with chemistry, physics, and mathematics. We designate Track C as an *integration-based learning* (IBL) curriculum. For ten years (2003 to 2013), FYE students at the college were taught in the three tracks [11].

1.1.1 The Foundation Coalition Curriculum

From 1993 to 2004, the National Science Foundation (NSF) funded the Foundation Coalition (FC) to reform and improve the education of FYE students. As presented in Fig. 1, the FC curriculum included the following four themes: integrated curriculum, active/cooperative learning, technology-enabled learning, and continuous improvement [17, 18]. Table 1 provides a detailed description of the two-semester FYE FC curriculum content.

Ideally, FC students would be co-enrolled in engineering, chemistry, physics, and mathematics with all faculty coordinating their teaching so topics are introduced in proper sequence. During the pilot studies with smaller numbers of students, this level of integration was achieved; however, it was impractical when FC was scaled up and implemented universally.

In addition to the four themes, the FC at the college included the following: (a) clustering students into "learning communities" who took common courses (math, engineering, and 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.

1.1.2 Engineering Accounting

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

As an integrated curriculum, the FC curriculum used engineering accounting to provide the following student benefits: (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 FC curriculum benefitted all engineering students and hence is suitable for the common curriculum [2, 16]. However, as stated earlier, most studies of the FC curriculum explored short-term effects rather than long-term effects on student performance.

1.2 Theoretical Framework: Logic Model for Theory of Change

The Theory of Change, popularized by Weiss [7], is a concept used to explain and evaluate changes at program or organization levels, and has frequently been used in sociology and political science for

Integrated curriculum: The FC curriculum integrates with both the first year and upperclassman years. To support the first 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."	**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).	**Continuous improvement:** The FC course is constantly evaluated to update the content and to improve delivery.

Fig. 1. Four themes of the FC curriculum.

Table 1. First-Year Engineering FC 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
Thermodynamics	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.

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

Source. Yoon et al. [32].

theory-driven evaluation [19]. In the practice of evaluation, Theory of Change considers several elements for change, such as inputs to initiate the change (e.g., learning environments and resources), activities that undertaken the change (e.g., interventions), and outcomes that resulted from the change (e.g., improved learning). The anticipated change can be evaluated by direct and indirect outcomes. The process of change involves short-term (*proximal*), intermediate (*medial*), and long-term (*distal*) effects on the chronological flow, along with causal relationships between them [6, 8, 9]. To illustrate the change, a logic model is frequently used to present inputs, activities, and outcomes on the pathways of the change framework [6, 20].

For example, engineering program goals are for students to (a) persist in engineering, (b) graduate with an engineering degree, (c) earn a good GPA, and (d) be equipped with soft and hard skills, as addressed in the Accreditation Board for Engineering and Technology (ABET) Student Outcomes [21, 22]. Ultimately, the objective is for engineering students to become enculturated as professional engineers [23]. According to the Theory of Change, formal engineering education is considered as inputs and activities, and graduation outcomes (e.g., graduation in engineering, time-to-graduation, and cumulative GPA) are outcomes. To evaluate the initiatives of the change in the FYE curriculum in a systematic and cumulative manner, this study applied the logic model for the Theory of Change to the engineering education program at the Southwestern university [8].

As an evaluation framework, this study utilizes the logic model for the Theory of Change (Fig. 2). The logic model considers the following: inputs (i.e., program components, such as student background and characteristics), activities (i.e., FYE curriculum track), proximal outcomes (i.e., FYE I and II course grades), and distal outcomes (i.e., graduation status in engineering). The Theory of Change components of this logic model are to (a) link the inputs and

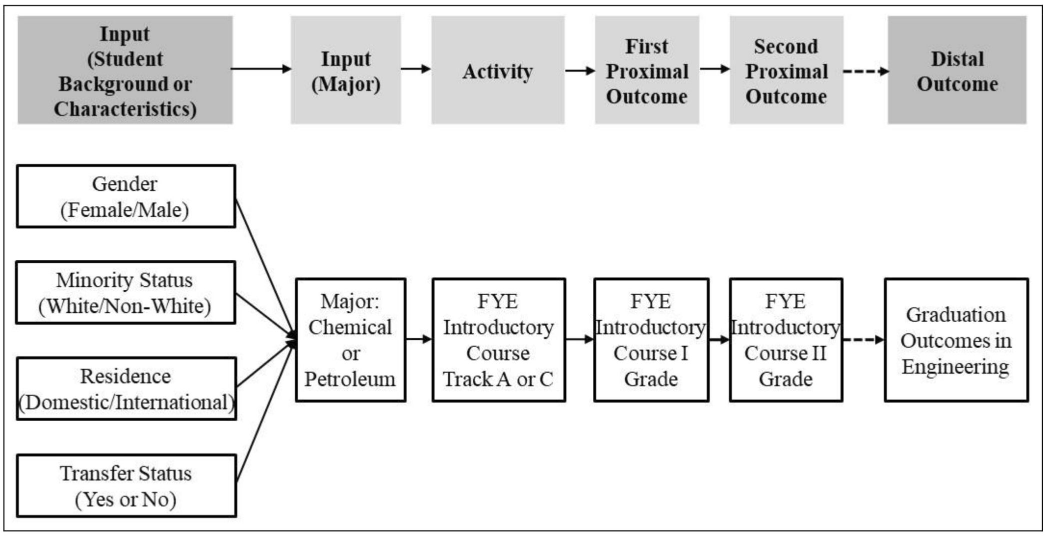

Fig. 2. The logic model for the Theory of Change to explore the FC curriculum effects.

outputs, (b) understand the connections between the components at each step toward the distal outcomes, and (c) unfold the effects of the FYE FC curriculum on student graduation outcomes.

Here, short-term outcomes (i.e., first and second proximal outcomes) are course grades from the direct impact of the FYE introductory courses, which may affect students' future performance in subsequent courses. In particular, course grades act as the catalyst for the long-term outcomes (i.e., graduation outcomes). In other words, long-term outcomes result from the accumulated short-term and intermediate outcomes during the course of the change. Note that long-term outcomes are easily affected by a variety of external factors, such as personal (e.g., psychological, financial, family issues, and social) and contextual factors on the pathway [5, 24, 25].

1.3 Purpose of the Study

By comparing student performance between Track A (PBL) vs. Track C (IBL), this study explored the longitudinal impacts of the FC curriculum on chemical and petroleum engineering students. To further explicate the link between the FC curriculum and its longitudinal effects on engineering students' graduation outcomes (i.e., distal outcomes, such as graduation in engineering, time-to-graduation, and cumulative GPA), we presented two studies of these two-semester courses. In Study I, students were divided into two groups: (1) those who took Track A in their first semester and (2) those who took Track C in their first semester. In Study II, students were divided into two groups: (1) those who took Track A in both semesters and (2) those who took Track C in both semesters. Study II shows the impact of complete immersion in Track A or Track C, and involved a smaller number of students than Study I. The following research questions guided both studies:

- What are the longitudinal effects of the FC curriculum on (a) graduation status in engineering, (b) time-to-graduation, and (c) cumulative GPA?
- What are the longitudinal effects of the FC curriculum along with student background (e.g., gender, race/ethnicity, residence, and admission status, etc.) on (a) graduation status in engineering, (b) time-to-graduation, and (c) cumulative GPA?

2. Methods

2.1 Setting

During each of the 2003 to 2007 school years (five cohorts) at the large Southwestern public university in the United States, the FYE introductory 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 two faculty members, one drawn from the engineering departments and one from the graphics department. The track designation of the class was determined by the faculty from the engineering departments. For example, if a mechanical engineering professor taught the class, it was designated Track A. Similarly, if a chemical engineering faculty taught the class, it was designated Track C. Graphics faculty taught across tracks and adapted their content to match the needs of the track.

During the 2003 to 2007 school years, during course registration, chemical and petroleum engineering students selected either Track A or Track C. 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 possible reasons: (a) there was a schedule conflict, (b) Track C was full, or (c) they wanted to change their major.

2.2 Participants

The target population of this study was students who started their major in chemical or petroleum engineering in fall 2003 through fall 2007 at the Southwestern public university and attempted to take the first FYE introductory course in their first fall semester. A total of 1,022 newly admitted students served as participants of Study I, which included 656 chemical engineering and 366 petroleum engineering students who took Track A or Track C. In Study I, 782 students achieved a valid credit for the first FYE introductory course in Track A or Track C and attempted to take the second FYE introductory course consecutively. Of these, 555 students stayed in the same track and were selected as participants in Study II. Table 3 shows their demographic characteristics in terms of gender (female vs. male), residence (domestic vs. international), race/ethnicity, admission type (first-time-in college [FTIC] vs. first-time-transfer [FTT]), curriculum track (Track A vs. Track C), and engineering major (chemical vs. petroleum).

In Study I, all 1,022 chemical and petroleum engineering students who took the FYE introductory course in their first fall semester upon entering the engineering program served as participants. In Study II, a subset of 555 students were selected who consecutively took the two FYE introductory courses in the same track. Therefore, Study I explored the impact of the first semester of the FC curriculum, and Study II explored the impact of two semesters of the FC curriculum.

Table 3. Demographic Characteristics of the Participants

Category	Study I						Study II					
	Total		Chemical		Petroleum		Total		Chemical		Petroleum	
	N	%	*n*	%	*n*	%	*N*	%	*n*	%	*n*	%
Gender												
Female	290	28.4	218	33.2	72	19.7	141	25.4	104	29.1	37	18.7
Male	732	71.6	438	66.8	294	80.3	414	74.6	253	70.9	161	81.3
Residence												
Domestic	966	94.5	626	95.4	340	92.9	521	93.9	343	96.1	178	89.9
International	56	5.5	30	4.6	26	7.1	34	6.1	14	3.9	20	10.1
Race/Ethnicity[a]												
Hispanic	109	11.3	80	12.2	29	7.9	54	10.4	42	12.2	12	6.1
American Indian or Alaska Native	3	0.3	3	0.5	0	0.0	3	0.6	3	0.9	0	0.0
Asian	51	5.3	36	5.5	15	4.1	29	5.6	19	5.5	10	5.1
Black	19	2.0	10	1.5	9	2.5	9	1.7	3	0.9	6	3.0
Native Hawaiian or other Pacific Islander	1	0.1	1	0.2	0	0.0	0	0.0	0	0.0	0	0.0
White	775	80.2	490	74.7	285	77.9	422	81.0	272	79.3	150	75.8
Multi-racial	8	0.8	6	0.9	2	0.5	4	0.8	4	1.2	0	0.0
Admission Type												
FTIC	921	90.1	578	88.1	343	93.7	493	88.8	314	88.0	179	90.4
FTT	101	9.9	78	11.9	23	6.3	62	11.2	43	12.0	19	9.6
Course Track												
A	555	54.3	376	57.3	179	48.9	241	43.4	168	47.1	73	36.9
C	467	45.7	280	42.7	187	51.1	314	11.2	189	52.9	125	63.1
Total	1,022	100.0	656	100.0	366	100.0	555	100.0	357	100.0	228	100.0

Note. [a] Race/Ethnicity was categorized for domestic students only; FTIC = First-time-in college; FTT = First-time-transfer.

2.3 Data Analyses

Retrieving data from the university archives, the participants' academic activities at the university were tracked from fall 2003 to fall 2016. According to the data, spring 2015 was the semester that showed participants' last academic activities, like graduating from the university. As indicators of student success in engineering, participants' graduation status in engineering, time-to-graduation in engineering, and cumulative GPA were the distal outcome variables in this study. Here, students' graduation status was categorized into one of three groups: (a) graduation in engineering, (b) graduation in non-engineering, and (c) no graduation. To calculate time-to-graduation in engineering, semesters were counted based on the institutional definition in which summer semesters were counted as fall semesters; therefore, only two semesters (i.e., fall and spring) were counted for each school year. In this quasi-experimental study, Track A students served as a control group (traditional project-based learning [PBL] curriculum) and Track C students served as a treatment group (integration-based learning [IBL] curriculum).

First, descriptive statistics were used to identify data trends as well as correlations. To answer the first research question, inferential statistics (e.g., correlations, chi-square tests, independent *t*-tests, two-way analysis of variances [ANOVAs]) were applied to check statistically significant differences between the two groups and among subgroups at alpha level of 0.05. All assumptions for inferential statistics (e.g., independent observation, normality, and homogeneity of variance) were checked and when any assumptions were violated, data were transformed. When applicable, effect sizes of the differences, such as Cohen's d and partial ω^2 were calculated [26, 27].

To answer the second research question (i.e., identifying significant predictors of student graduation outcomes in engineering), we used several hierarchical logistic regression models with three different outcome variables (i.e., graduation status in engineering, time-to-graduation, and cumulative GPA). For predictors, we considered six endogenous variables: gender (male = 0, female = 1), minority status (White = 0, non-White = 1), admission type (first-time-in college = 0, first-time-transfer = 1), major (petroleum = 0, chemical = 1), track (A = 0, C = 1), and grades of the introductory courses (A = 5, B = 4, C = 3, D = 2, F = 1, Withdraw/Drop = 0). Although the two FYE introductory course grades can serve as proximal outcomes, we only utilized distal outcomes as exogenous variables because we focused on the longitudinal impact. For distal outcome variables, graduation status was binary (no graduation in engineering = 0, graduation in engineering = 1) and the other two outcome variables (time-to-graduation and cumulative GPA) were continuous. Before the analyses, the assumptions for the multiple regressions (e.g., linearity, independence of errors, and multicollinearity) were checked. Nagelkerke's R^{2_N} was utilized to assess the model fits and Wald statistics were used to assess the contribution of predictors to the final logistic regression model [27]. The same data analyses were applied in both Study I and Study II.

3. Results – Study I

3.1 Correlations among Variable of Interests

Table 4 shows correlation coefficients among variables of interests (e.g., gender, minority status, residence, transfer status, major, track, and FYE introductory course final grade) and three graduation outcome variables (e.g., graduation status in engineering, time-to-graduation in engineering in semester, and cumulative GPA). The negative correlation coefficients on cumulative GPA indicate that male, minority, or first-time transfer (FTT) students tended to have a lower cumulative GPA than their counterparts, but the effect sizes were all small. International or FTT students tended to take less time to graduate in engineering compared to their counterparts, but the effect sizes were small too. As expected, final grade from the first-semester FYE introductory course was significantly correlated with cumulative GPA (r = 0.581), followed by graduation status in engineering (r = 0.413). As expected, students with a higher cumulative GPA tended to take less time to graduate in engineering, and the effect sizes were all moderate. Regarding the first proximal outcome, FTT, petroleum engineering, or Track C students tended to have lower final grades than their counterparts, but the effect sizes were small.

3.2 Graduation Status in Engineering

Among the total of 1,022 students in this study, 65.7% (n = 671) graduated in engineering, 19.4% (n = 198) graduated in non-engineering, and 15.0% (n = 153) did not graduate. Fig. 3 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 by track as a whole, $\chi^2(1) = 0.01$, $p = 0.936$, and for each engineering program, $\chi^2(1) = 0.04$, $p = 0.849$ for chemical engineering majors, and $\chi^2(1) = 0.39$, $p = 0.534$ for petroleum engineering majors.

3.3 Time-to-Graduation in Engineering

On average, students took 4.5 years to graduate in engineering (n = 671, M = 9.00, SD = 1.33). Fig. 4 delineates the average time-to-graduation by major and track. A two-way analysis of variance (ANOVA) showed that there were no significant main effects of track and major on the participants' time-to-graduation in engineering: $F(1, 667) = 0.4$, $p = 0.552$, partial $\eta^2 = 0.001$ for track and $F(1, 667) = 1.2$, $p = 0.274$, partial $\eta^2 = 0.02$ for major. There was no significant interaction effect between track and major with $F(1, 667) = 0.9$, $p = 0.331$, partial $\eta^2 = 0.001$, either. The above results imply that the average time-to-graduation in engineering differed by neither track nor major. In detail, even though average time-to-graduation of Track C students (n = 306, M = 8.97, SD = 1.35) was slightly shorter than Track A students (n = 365, M = 9.02, SD = 1.31), the difference of 0.05 semester was not statistically significant. Similarly, chemical engi-

Table 4. Correlations among Variables of Interests and Three Graduation Outcome Variables

Variable	7	8	9	10
1. Gender (0 = female, 1 = male)	–0.044	–	0.083*	–0.143*
2. Minority (0 = White, 1 = non-White)	–0.049	–	0.029	–0.108*
3. Residence (0 = domestic, 1 = international)	0.018	–	–0.136*	0.034
4. Transfer Status (0 = FTIC, 1 = FTT)	–0.067*	–	–0.262*	–0.083*
5. Major (0 = petroleum, 1 = chemical)	0.072*	–	0.013	0.108*
6. Track (0 = A, 1 = C)	–0.076*	–	–0.012	0.045
7. FYE Introductory Course I Final Grade	1.000	0.413*	–0.208*	0.581*
8. Graduation Status in Engineering (0 = no graduation in engineering, 1 = graduation in engineering)	–	1.000	–0.017	0.416*
9. Time-to-Graduation in Engineering (in semester)	–	–	1.000	–0.383*
10. Cumulative GPA	–	–	–	1.000

Note. * $p < 0.05$; "–" denotes not applicable. FYE = first-year engineering.

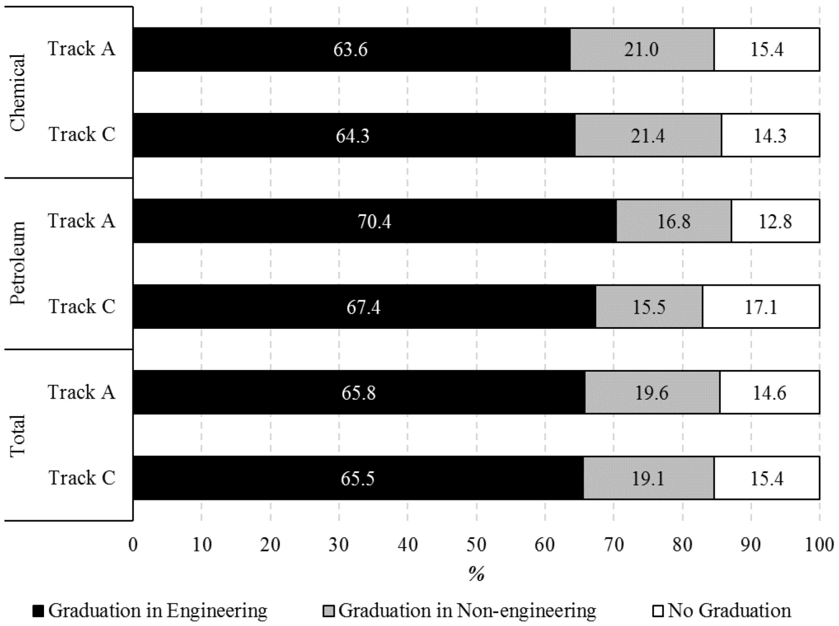

Fig. 3. Graduation status of chemical and petroleum engineering students by track.

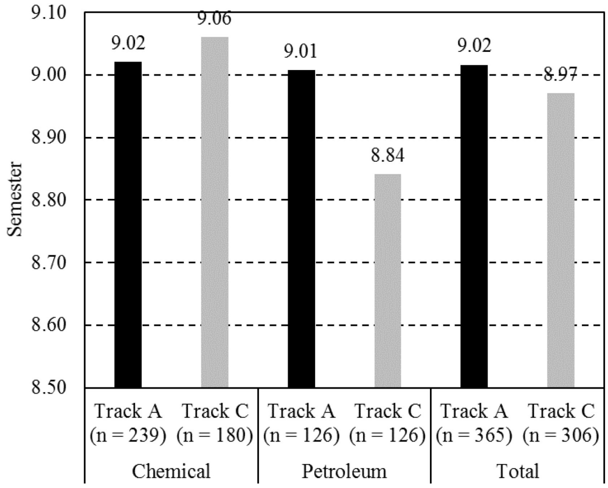

Fig. 4. Average time-to-graduation in engineering by major and track.

neering students' average time-to-graduation (n = 419, M = 9.04, SD = 1.39) was longer than petroleum engineering students (n = 252, M = 8.92, SD = 1.21). The difference of 0.12 semester was not statistically significant.

3.4 Cumulative GPA by the Time of Graduation in Engineering

The cumulative GPA of students who graduated in engineering was on average 3.19 (n = 671, SD = 0.48). Fig. 5 delineates the average cumulative GPAs by major and track. A two-way analysis of variance (ANOVA) revealed that there was significant main effect of major on cumulative GPAs of the participants when they graduated in engineering with $F(1, 667) = 26.2$, $p < 0.001$, partial $\eta^2 = 0.038$. The main effect of track was not significant with $F(1, 667) = 3.5$, $p = 0.061$, partial $\eta^2 = 0.005$. However, the interaction effect between major and track was statistically significant with $F(1, 667) = 5.7$, $p = 0.017$, partial $\eta^2 = 0.008$.

In detail, the average cumulative GPA of chemical engineering students (n = 419, M = 3.26, SD = 0.46) was significantly higher than petroleum engineering students (n = 252, M = 3.08, SD = 0.48) with 0.18 point difference, $t(669) = 4.8$, $p < 0.001$, Cohen's d = 0.38, which indicates a medium effect (Cohen, 1988). However, average cumulative GPA of all Track C students (n = 306, M = 3.23, SD = 0.48) was not significantly different from all Track A students (n = 365, M = 3.16, SD = 0.47) with a 0.07 point difference.

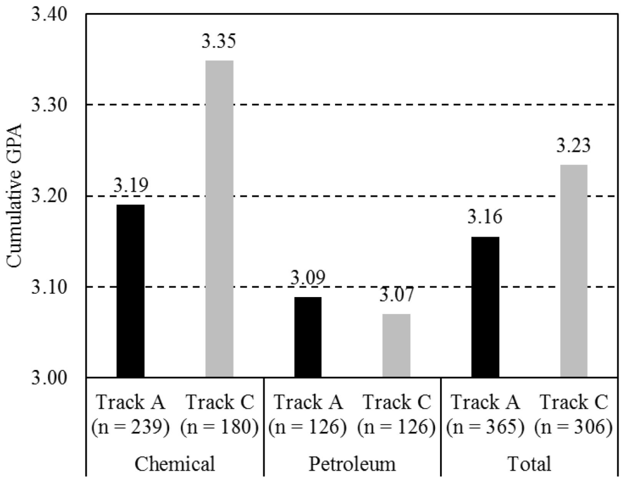

Fig. 5. Average cumulative GPAs of participants who graduated in engineering by major and track.

As indicated by Fig. 5, there was a significant interaction effect between major and track. Track C chemical engineering students (n = 180, M = 3.35, SD = 0.44) tended to have a higher cumulative GPA than Track A chemical engineering students (n = 239, M = 3.19, SD = 0.46) with a 0.16 point difference, $t(417) = 3.5$, $p < 0.001$, Cohen's d = 0.35, which indicates a medium effect (Cohen, 1988). This trend was not shown in petroleum engineering students.

3.5 Predictability of the One-Semester FC Curriculum on Students' Long-Term Outcomes

3.5.1 Graduation Status in Engineering

Table 5 shows the results from a binary logistic regression model when the first three variables were entered into the model first and then the other three variables were added as new predictors. Here, the significant Wald statistic indicates that gender, major, and FYE introductory course I final grade were significant predictors of students' graduation in engineering. When all other conditions were the same, the positive B coefficient indicates that male students tended to graduate in engineering at a significantly higher rate than did female students. Furthermore, those students who achieved a higher final grade had a higher probability of graduating in engineering. When all other conditions are the same, the negative B coefficient indicates that students who started in petroleum engineering tended to graduate in engineering with a significantly higher rate than students who started with chemical engineering. Here, minority status, admission type, and track are not statistically significant predictors. The regression model with six predictors shows a prediction rate of 73.4% correct.

3.5.2 Time-To-Graduation

Table 6 shows the results from a multiple regression model using six endogenous variables as predictors of time-to-graduation. Here, admission type, major, track, and final grade were significant predictors of students' time-to-graduation in engineering. When all other conditions were equal, the negative unstandardized B/standardized Beta indicates that first-time-transfer (FTT) students, or Track C students, or students with higher final grade took shorter time to graduate in engineering

Table 5. Hierarchical Logistic Regression Analysis Predicting Students' Graduation in Engineering with Six Endogenous Variables

							95% CI for *Exp(B)*	
Predictor	***B***	***SE***	***Wald***	***df***	***p***	***Exp(B)***	***Lower***	***Upper***
Constant	–2.55	0.33	59.66	1	< 0.001	0.08	–	–
Gender (0 = female, 1 = male)	0.63	0.17	13.69	1	< 0.001	1.87	1.34	2.61
Minority (0 = White, 1 = non-White)	–0.08	0.19	0.18	1	0.672	0.92	0.64	1.33
Admission Type (0 = FTIC, 1 = FTT)	0.29	0.28	1.01	1	0.315	1.33	0.76	2.33
Major (0 = petroleum, 1 = chemical)	–0.36	0.16	4.77	1	0.029	0.70	0.51	0.96
Track (0 = A, 1 = C)	0.19	0.15	1.59	1	0.208	1.21	0.90	1.64
FYE Introductory Course I Final Grade	1.11	0.10	134.90	1	< 0.001	3.03	2.51	3.66

Note. FTIC = first-time-in college; FTT = first-time transfer; FYE = first-year engineering; *Exp(B)* = odds ratio; CI = confidence interval; Nagelkerke's R^2_N = 0.26, Model $\chi^2(1)$ = 11.51; "–" denotes not applicable.

Table 6. Multiple Regression Analysis Predicting Students' Time-To-Graduation in Engineering with Six Endogenous Variables

Predictor	*B*	*SE*	*Beta*	*t*	*p*	95% CI for *B*		*r*	*T*	*VIF*
						Lower	*Upper*			
Constant	10.60	0.25		43.2	< 0.001	10.12	11.09	–	–	–
Gender (0 = female, 1 = male)	0.06	0.11	0.02	0.5	0.596	–0.16	0.28	0.045	0.971	1.030
Minority (0 = White, 1 = non-White)	0.07	0.13	0.02	0.6	0.551	–0.17	0.32	0.029	0.981	1.019
Admission Type (0 = FTIC, 1 = FTT)	–1.30	0.19	–0.26	–6.9	< 0.001	–1.67	–0.93	–0.213	0.961	1.041
Major (0 = petroleum, 1 = chemical)	0.36	0.10	0.13	3.5	< 0.001	0.16	0.56	0.055	0.947	1.056
Track (0 = A, 1 = C)	–0.25	0.10	–0.09	–2.5	0.012	–0.44	–0.05	–0.041	0.972	1.029
FYE Introductory Course I Final Grade	–0.55	0.07	–0.31	–8.2	< 0.001	–0.68	–0.42	–0.269	0.944	1.059

Note. FTIC = first-time-in college; FTT = first-time transfer; FYE = first-year engineering; B = unstandardized parameter; Beta = standardized parameter; CI = confidence interval; *r* = zero-order correlation coefficient; *T* = Tolerance; *VIF* = Variance inflation factor; "–" denotes not applicable.

than their counterparts. The positive unstandardized B/standardized Beta indicates that students who started in chemical engineering took longer to graduate in engineering than students who started with petroleum engineering. Gender and minority status were not statistically significant predictors of time-to-graduation in engineering. According to the standardized Betas, FYE introductory course final grade was the strongest predictor of students' time-to-graduation in engineering, followed by admission type, major, and track. The regression model explained 14.4% of variance accounted by the predictors in the data (R^2 = 0.152; Adjusted R^2 = 0.144).

3.5.3 Cumulative GPA

Table 7 shows the results from a multiple regression model using six endogenous variables as predictors of cumulative GPA. Here, gender, admission type, major, track, and final grade were significant predictors of students' cumulative GPA when they graduated in engineering. When all other conditions were equal, the negative unstandardized B/standardized Beta indicates that female and first-time-in college (FTIC) students tended to have higher cumulative GPAs than their counterparts. The positive unstandardized B/standardized Beta indicates that students who started with chemical engineering and Track C students tended to have higher cumulative GPA than their counterparts. By nature, students with a higher final grade achieved higher cumulative GPAs when they graduated in engineering. Student minority status is not a statistically significant predictor of cumulative GPA. According to the standardized Betas, final grade was the strongest predictor of students' cumulative GPA, followed by track, gender, admission type, and major. The regression model explained 37.9% of variance accounted by the predictors in the data (R^2 = 0.379; adjusted R^2 = 0.373).

4. Results – Study II

4.1 Correlations among Variable of Interests

Table 8 shows correlation coefficients among variables of interests (e.g., gender, minority status, residence, transfer status, major, track, and FYE introductory course II final grade) and three graduation outcome variables (e.g., graduation status in engineering, time-to-graduation in engineering in semester, and cumulative GPA). As expected, the correlation trends in cumulative GPA and time-to graduation in engineering were similar to the ones in Table 4. Similarly, FYE introductory course II

Table 7. Multiple Regression Analysis Predicting Students' Cumulative GPA in Engineering with Six Endogenous Variables

Predictor	*B*	*SE*	*Beta*	*t*	*p*	95% CI for *B*		*r*	*T*	*VIF*
						Lower	*Upper*			
Constant	2.15	0.08		27.8	< 0.001	2.00	2.31	–	–	–
Gender (0 = female, 1 = male)	–0.14	0.04	–0.12	–3.8	< 0.001	–0.21	–0.07	–0.185	0.971	1.030
Minority (0 = White, 1 = non-White)	–0.06	0.04	–0.05	–1.4	0.151	–0.13	0.02	–0.088	0.981	1.019
Admission Type (0 = FTIC, 1 = FTT)	–0.21	0.06	–0.11	–3.6	< 0.001	–0.33	–0.09	–0.149	0.961	1.041
Major (0 = petroleum, 1 = chemical)	0.10	0.03	0.10	3.2	0.001	0.04	0.17	0.179	0.947	1.056
Track (0 = A, 1 = C)	0.13	0.03	0.14	4.3	< 0.001	0.07	0.19	0.089	0.972	1.029
FYE Introductory Course I Final Grade	0.35	0.02	0.54	16.6	< 0.001	0.31	0.39	0.563	0.944	1.059

Note. FTIC = first-time-in college; FTT = first-time transfer; FYE = first-year engineering; B = unstandardized parameter; Beta = standardized parameter; CI = confidence interval; *r* = zero-order correlation coefficient; *T* = Tolerance; *VIF* = Variance inflation factor; "–" denotes not applicable.

final grade was significantly correlated with cumulative GPA (r = 0.494), followed by graduation status in engineering (r = 0.365). Regarding the second proximal outcome, petroleum engineering students tended to have lower final grades than their counterparts, but the effect size was small. Different from the findings from the correlation matrix in Table 4, the correlation of the final grade with transfer status was not significant anymore and Track C students tended to have higher course grade than Track A students, but the effect sizes were all small.

4.2 Graduation Status in Engineering

Among the total of 555 students in Study II, 78.6% (n = 436) graduated in engineering, 12.8% (n = 71) graduated in non-engineering, and 8.6% (n = 48) did not graduate. 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 no significant associations of graduation status by track as a whole, $\chi^2(1) = 1.40$, $p = 0.236$. When the data were disaggregated by major, there was no significant difference by track in graduation status for chemical engineering students, $\chi^2(1) = 0.02$, $p = 0.896$, but a significant difference existed for petroleum engineering majors, $\chi^2(1) = 8.02, p = 0.005$. As shown in Fig. 6, for petroleum engineering majors, Track A students (93.2%) revealed a higher graduation rate than Track C students (77.6%).

4.3 Time-to-Graduation in Engineering

Similar to Study I, on average, students took 4.5 years to graduate in engineering (n = 436, M = 8.90, SD = 1.33). Fig. 7 delineates the average time-to-graduation by major and track. 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, $F(1, 432) = 6.0, p = 0.015$, partial $\eta^2 = 0.014$, but no significant main effect of track, $F(1, 432) = 0.2, p = 0.665$, partial η^2 <

Table 8. Correlations among Variables of Interests and Three Graduation Outcome Variables

Variable	7	8	9	10
1. Gender (0 = female, 1 = male)	0.051	–	0.028	–0.220*
2. Minority (0 = White, 1 = non-White)	–0.070	–	0.012	–0.037
3. Residence (0 = domestic, 1 = international)	0.032	–	–0.115*	0.001
4. Transfer Status (0 = FTIC, 1 = FTT)	–0.050	–	–0.282*	–0.156*
5. Major (0 = petroleum, 1 = chemical)	0.109*	–	0.099*	0.075
6. Track (0 = A, 1 = C)	0.087*		–0.024	0.092*
7. FYE Introductory Course II Final Grade	1.000	0.285*	–0.168*	0.494*
8. Graduation Status in Engineering (0 = no graduation in engineering, 1 = graduation in engineering)	–	1.000	–0.025	0.365*
9. Time-to-Graduation in Engineering (in semester)	–	–	1.000	–0.288*
10. Cumulative GPA	–	–	–	1.000

Note. *p < 0.05; "–" denotes not applicable.

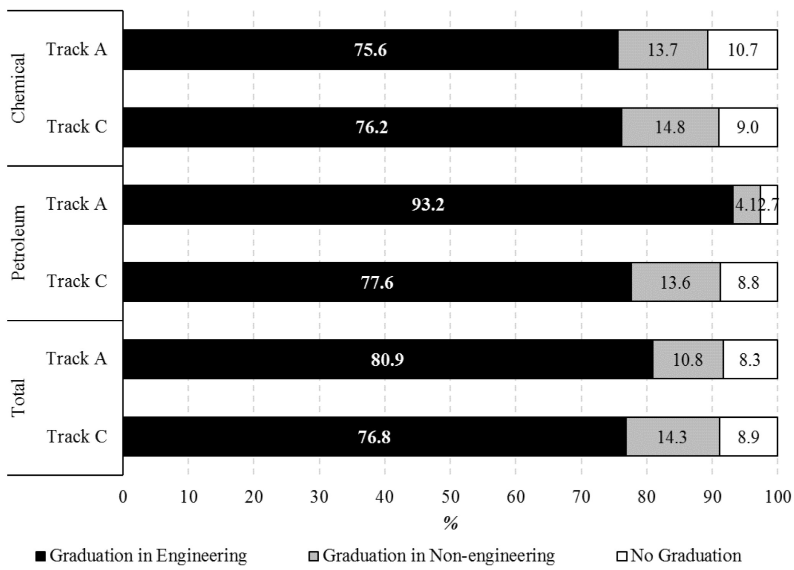

Fig. 6. Graduation status of chemical and petroleum engineering students by track.

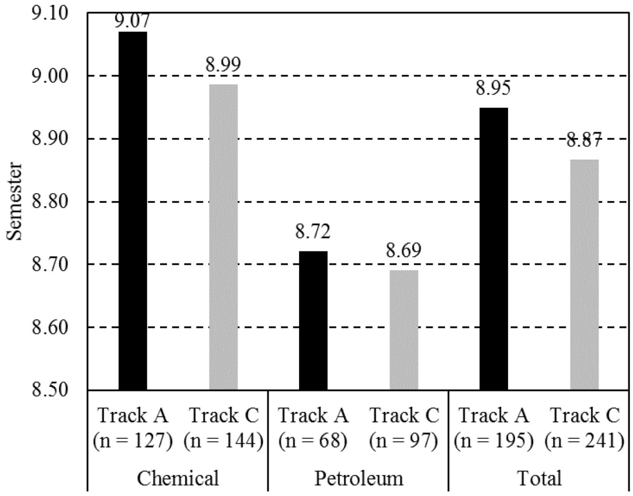

Fig. 7. Average time-to-graduation in engineering by major and track.

0.001. There was no significant interaction effect between track and major with $F(1, 432) = 0.04$, $p = 0.835$, partial $\eta^2 < 0.001$, either. The above results imply that the average time-to-graduation in engineering did differ by major. In detail, even though average time-to-graduation of Track C students ($n = 241$, $M = 8.87$, $SD = 1.35$) was slightly shorter than Track A students ($n = 195$, $M = 8.95$, $SD = 1.30$, the difference of 0.08 semester was not statistically significant. Nonetheless, chemical engineering students' average time-to-graduation ($n = 271$, $M = 9.03$, $SD = 1.43$) was longer than petroleum engineering students ($n = 165$, $M = 8.70$, $SD = 1.13$). The difference of 0.33 semester was statistically significant with Cohen's $d = 0.25$.

4.4 Cumulative GPA by the Time of Graduation in Engineering

The cumulative GPA of all students who graduated in engineering was on average 3.23 ($n = 436$, $SD = 0.46$). Fig. 8 delineates the average cumulative GPAs by major and track. A two-way analysis of variance (ANOVA) revealed that there were significant main effects of major and track on cumulative GPAs of the participants when they graduated in engineering: $F(1, 432) = 8.9$, $p = 0.003$, partial $\eta^2 = 0.020$ for major and $F(1, 432) = 5.2$, $p = 0.023$, partial $\eta^2 = 0.012$ for track. In addition, the interaction effect between major and track was statistically significant with $F(1, 432) = 9.3$, $p = 0.002$, partial $\eta^2 = 0.021$.

In detail, average cumulative GPA of chemical engineering students ($n = 271$, $M = 3.28$, $SD = 0.45$) was significantly higher than petroleum engineering students ($n = 165$, $M = 3.14$, $SD = 0.46$) with 0.14 point difference, $t(434) = 3.2$, $p = 0.001$, Cohen's $d = 0.31$, which indicates a medium effect (Cohen, 1988). In addition, average cumulative GPA of Track C students ($n = 241$, $M = 3.29$, $SD = 0.46$) was significantly higher than Track A students ($n = 195$, $M = 3.16$, $SD = 0.44$) with a 0.13 point difference, $t(434) = 2.9$, $p = 0.004$, Cohen's $d = 0.29$, which indicates a medium effect (Cohen, 1988). As apparent in Fig. 8, there is a

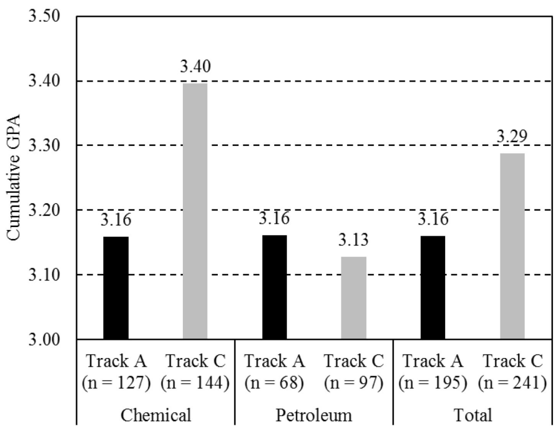

Fig. 8. Average cumulative GPAs of participants who graduated in engineering by major and track.

Table 9. Hierarchical Logistic Regression Analysis Predicting Students' Graduation in Engineering with Six Endogenous Variables

Predictor	*B*	*SE*	*Wald*	*df*	*p*	*Exp(B)*	95% CI for *Exp(B)*	
							Lower	*Upper*
Constant	–0.60	0.47	1.61	1	0.205	0.55	–	–
Gender (0 = female, 1 = male)	0.18	0.25	0.49	1	0.483	1.20	0.73	1.97
Minority (0 = White, 1 = non-White)	0.12	0.29	0.17	1	0.676	1.13	0.64	2.00
Admission Type (0 = FTIC, 1 = FTT)	–0.12	0.39	0.09	1	0.764	0.89	0.42	1.90
Major (0 = petroleum, 1 = chemical)	–0.76	0.26	8.58	1	0.003	0.47	0.28	0.78
Track (0 = A, 1 = C)	–0.38	0.23	2.72	1	0.099	0.68	0.43	1.07
FYE Introductory Course II Final Grade	0.85	0.13	40.57	1	< 0.001	2.34	1.80	3.05

Note. FTIC = first-time-in college; FTT = first-time transfer; FYE = first-year engineering; *Exp(B)* = Odds ratio; CI = confidence interval; Nagelkerke's R^2_N = 0.15, Model $\chi^2(6)$ = 64.0; "–" denotes not applicable.

significant interaction effect between major and track. Track C chemical engineering students (n = 144, M = 3.40, SD = 0.42) tended to have a higher cumulative GPA than Track A chemical engineering students (n = 127, M = 3.16, SD = 0.46) with a 0.24 point difference, $t(269) = 4.5$, $p < 0.001$, Cohen's d = 0.55, which indicates a large effect (Cohen, 1988).

4.5 Predictability of the Two-Semester FC Curriculum on Students' Long-Term Outcomes

4.5.1 Graduation Status in Engineering

Table 9 shows the results from a binary logistic regression model when the first three variables were entered into the model first and then the other three variables were added as new predictors. Here, the significant Wald statistic indicates that major and final grade were significant predictors of students' graduation in engineering. When all the other conditions are the same, the positive *B* coefficient indicates that students with a higher final grade had higher probability of graduating in engineering. When all other conditions are the same, the negative *B* coefficient indicates that students who started with petroleum engineering tended to graduate in engineering with a significantly higher rate than students who started with chemical engineering. Here, gender, minority status, admission type, track were not statistically significant predictors. The regression model with six predictors showed a prediction rate of 78.5% correct.

4.5.2 Time-To-Graduation

Table 10 shows the results from a multiple regression model using six endogenous variables as predictors of time-to-graduation. Here, admission type, major, and final grade were significant predictors of students' time-to-graduation in engineering. When all the other conditions were equal, the negative unstandardized B/standardized Beta indicate that first-time-transfer (FTT) students, or students with higher final grade took shorter time to graduate in engineering than their counterparts. Gender, minority status, and track were not statistically significant predictors of time-to-graduation in engineering. According to the standardized Betas, admission type was the strongest predictor of students' time-to-graduation in engineering, followed by final grade and major. The regression model explained 12.7% of variance accounted by the predictors in the data (R^2 = 0.127; Adjusted R^2 = 0.116)

4.5.3 Cumulative GPA

Table 11 shows the results from a multiple regression model using six endogenous variables as pre-

Table 10. Multiple Regression Analysis Predicting Students' Time-To-Graduation in Engineering with Six Endogenous Variables

Predictor	*B*	*SE*	*Beta*	*t*	*p*	95% CI for *B*		*r*	*T*	*VIF*
						Lower	*Upper*			
Constant	9.75	0.25	–	38.4	< 0.001	9.25	10.25	–	–	–
Gender (0 = female, 1 = male)	0.19	0.13	0.06	1.4	0.152	–0.07	0.45	0.023	0.971	1.030
Minority (0 = White, 1 = non-White)	0.04	0.15	0.01	0.3	0.800	–0.25	0.33	0.012	0.985	1.015
Admission Type (0 = FTIC, 1 = FTT)	–1.35	0.21	–0.28	–6.4	< 0.001	–1.77	–0.94	–0.243	0.971	1.030
Major (0 = petroleum, 1 = chemical)	0.47	0.12	0.17	3.8	< 0.001	0.23	0.71	0.107	0.947	1.056
Track (0 = A, 1 = C)	–0.13	0.12	–0.05	–1.1	0.262	–0.36	0.10	–0.042	0.976	1.024
FYE Introductory Course II Final Grade	–0.34	0.07	–0.21	–4.9	< 0.001	–0.48	–0.21	–0.175	0.960	1.042

Note. FTIC = first-time-in college; FTT = first-time transfer; FYE = first-time engineering; B = unstandardized parameter; Beta = standardized parameter; CI = confidence interval; *r* = zero-order correlation coefficient; *T* = Tolerance; *VIF* = Variance inflation factor; "–" denotes not applicable.

Table 11. Multiple Regression Analysis Predicting Students' Cumulative GPA in Engineering with Six Endogenous Variables

Predictor	*B*	*SE*	*Beta*	*t*	*p*	95% CI for *B*		*r*	*T*	*VIF*
						Lower	*Upper*			
Constant	2.38	0.09		25.6	< 0.001	2.19	2.56		–	–
Gender (0 = female, 1 = male)	–0.34	0.05	–0.25	–6.8	< 0.001	–0.43	–0.24	–0.236	0.974	1.027
Minority (0 = White, 1 = non-White)	–0.03	0.05	–0.02	–0.6	0.557	–0.14	0.08	–0.037	0.979	1.021
Admission Type (0 = FTIC, 1 = FTT)	–0.27	0.08	–0.13	–3.5	0.001	–0.42	–0.12	–0.165	0.973	1.028
Major (0 = petroleum, 1 = chemical)	0.01	0.05	0.00	0.1	0.899	–0.08	0.10	0.068	0.956	1.046
Track (0 = A, 1 = C)	0.04	0.04	0.04	1.0	0.320	–0.04	0.13	0.098	0.973	1.027
FYE Introductory Course II Final Grade	0.33	0.03	0.49	13.2	< 0.001	0.28	0.38	0.488	0.969	1.032

Note. FTIC = First-time-in college; FTT = First-time transfer; B = unstandardized parameter; Beta = standardized parameter; CI = confidence interval; *r* = zero-order correlation coefficient; *T* = Tolerance; *VIF* = Variance inflation factor; "–" denotes not applicable.

dictors of cumulative GPA. Here, gender, admission type, and final grade were significant predictors of students' cumulative GPA when they graduated in engineering. When all the other conditions were equal, the negative unstandardized B/standardized Beta indicates that female and first-time-in college (FTIC) students tended to have higher cumulative GPAs than their counterparts. By nature, students with a higher final grade had a higher cumulative GPA when they graduated in engineering. Student minority status, major, and track were not statistically significant predictors of cumulative GPA. According to the standardized Betas, final grade was the strongest predictor of students' cumulative GPA, followed by gender and admission type. The regression model explained 32.2% of variance accounted by the predictors in the data (R^2 = 0.322; Adjusted R^2 = 0.314).

5. Discussion

5.1 Effect of the FC Curriculum on Chemical and Petroleum Engineering Students

Based on the logic model for the Theory of Change [6–10], this study adopts a retrospective approach to explore the longitudinal effect of the one-year FC curriculum on three different graduate outcomes of chemical and petroleum engineering students. When the quasi-experimental conditions (major and track) were only considered in the analyses using ANOVAs, several findings are of interest:

- Graduation in engineering – Petroleum engineering students taking Track A had higher graduation rates than students taking Track C, but there was no significant difference in chemical engineering students by track.
- Time to graduate in engineering – Among students who took one-year FYE introductory courses, on average, chemical engineering students took longer than petroleum engineering students, regardless of track. Within a discipline, there was no statistically significant difference from taking Track A vs. Track C.
- Cumulative GPA – For chemical engineering students who graduated in engineering, Track C improved cumulative GPA more than Track A. The effect was accentuated when two courses were taken within a given track (effect size of 0.55). For petroleum engineers, there was no difference between Track C and Track A.

Overall, the following statements can be made:

- For petroleum engineers, Track A students showed improved graduation rates; the effect was more pronounced with two semesters of Track A. All other factors (time-to-graduation, cumulative GPA) were unaffected.
- For chemical engineers, Track C students showed improved cumulative GPA; the effect was more pronounced with two semesters of Track C. All other factors (graduation rate, time-to-graduation) were unaffected.

These seemingly contradictory results can be explained via the following hypothesis: The chemical engineering curriculum is dominated by pure science (physics, chemistry, and biology) and engineering science (e.g., fluids, heat/mass transfer, reaction kinetics, thermodynamics, etc.), all of which are highly integrated and benefit from IBL (Track C). In contrast, the petroleum engineering curriculum places greater emphasis on engineering practice that is unique to their discipline (e.g., well drilling, testing, logging, and completion) and benefits less from IBL. In contrast, petroleum engineering benefits from PBL (Track A). Numerous studies show that "high-impact learning" – of which PBL is an example – improves retention of knowledge and for graduation [3, 28].

From 2003 to 2007, although there were different tracks in the FYE introductory courses, the FYE curriculum was substantially the same for all engineering majors (e.g., physics, chemistry, calculus) [21]. However, after the second year, the curriculum for each major has different numbers of credits for graduation. Petroleum engineering students had three to six fewer required credits than chemical engineering students. In part, this helps explain the significant difference in time-to-graduation between the two disciplines.

The better cumulative GPA of chemical engineering students taking Track C rather than Track A implies that the first-year FC curriculum impacts performance in upper-level courses. A follow-up study is warranted to investigate the causal link between the first-year FC curriculum and performance in individual upper-level courses (e.g., thermodynamics).

5.2 Predictability of FC Curriculum Along With Other Background Variables

When background variables (e.g., gender, minority status, and admission type) were considered together in the regression models, the significant variables that predict graduation outcomes were different. Overall, female or FTIC students tended to have higher cumulative GPAs than their counterparts, but FTT students tended to take shorter time to graduate in engineering and had equivalent graduation rates in engineering with FTIC students. These results are similar to the findings by Yoon et al. [21] using one-cohort FYE student data at the same university.

Interestingly, more significant predictors of graduation outcomes were found in Study I than Study II. In Study I, the FC curriculum effect was significant for the cumulative GPA and time-to-graduation. In other words, Track C students tended to have shorter time to graduate in engineering and had higher cumulative GPA, regardless of major. However, in Study II, the FC curriculum effect was not significant on cumulative GPA and time-to-graduation. In both Studies I and II, the FC curriculum effect was not a significant predictor of graduation in engineering.

On one hand, these results imply that first-semester student performance is a better indicator of future performance than second-semester student performance. Therefore, it is critical to provide necessary support for students who might be at risk on their future performance based on their first-semester course performance. On the other hand, as we utilized the second-semester data of students who already passed the first course, there might be a screening effect. In other words, participants in Study II were already qualified or screened for the potential to perform well in the subsequent courses. Therefore, because of the homogenous characteristics of Study II participants compared to Study I participants, it becomes more difficult to see the significance of the FC curriculum effects on student graduation outcomes.

This study attempts to evaluate the impact of the FC curriculum on the longitudinal student outcomes using proximal outcomes (first- and second-semester FYE introductory course grades). However, as acknowledged in the Theory of Change, change is not a linear process but requires many feedback loops to better understand the context and improvement on the pathways [29]. The practice of theory-driven evaluations was prominent for a few decades [29]. Unfortunately, in the engineering education literature, there has been a lack of research on the long-term effects of innovations, mostly due to the limit in funds and time. To overcome those limitations, there is a need for longitudinal studies to explore the impact of change through "theory-based evaluation in practice" [30]. This can be done by planning in advance, collecting data on the processes, identifying adequate or inadequate components of the intermediary change, and decision making about the sustainability of such innovation and efforts [30]. By systematically tracking each step, the engineering education community can develop and accumulate knowledge of research-based evidence for each innovation.

5.3 Limitations of the Study and Suggestions for Future Research

This retrospective study has several limitations. First, because of the use of status-quo data, randomization of the participants into tracks was not possible. Second, even though we framed our study based on the logic model for the Theory of Change, we cannot prove causal relationships between inputs and outputs. A common limitation in longitudinal studies is that long-term outcomes can be affected by a variety of known and unknown external factors. In other words, many factors not considered in this study might strongly impact the outcomes. Third, we did not consider intermediate outcomes at the sophomore, junior, and senior levels. There is a "need for data collection at multiple time points" on the pathway to outcomes [24]. Fourth, because of the data aggregated across five years and the natural characteristics of longitudinal studies, time could be a confounder that makes it difficult to isolate the true effect of the intervention on the outcomes because time could be responsible for some of the effects on student performance [31]. Finally, although we compared performance between chemical and petroleum engineering students, we acknowledge that each engineering program has a different criteria for student acceptance, varied curriculum, and different faculty with their own grading standards; thus, differences in student performance by major is expected. In addition, in this study, because of the limited sample size, we did not incorporate possible impacts of different instructional strategies across years.

5.4 Conclusions

This study shows the extent to which a FYE curriculum impacts engineering students' graduation outcomes, in terms of graduation in engineering, time-to-graduation, and cumulative GPA. In addition, because the two tracks for the first-year engineering students showed slightly different graduation outcomes by major, this study shows that when a FYE curriculum is specifically tailored to each major, there can be significant impact on student outcomes upon their graduation. In the case of the implementation of the first-year FC curriculum, the final GPA of chemical engineering students greatly improved from IBL (Track C) and the graduation rate of petroleum engineering students greatly improved from PBL (Track A). Given the critical nature of the FYE curriculum, further research is needed to address the efficiency and efficacy of FYE program from the perspective of students, educators, practitioners, researchers, and policy makers.

Acknowledgements – This article is based in part on a paper that was presented at the 124th American Society for Engineering Education Annual Conference and Exposition, Columbus, OH, WA, USA in 2017. The authors are grateful to Dr. Bonnie Dunbar for providing financial support and administrative leadership for this project. Furthermore, we are grateful to Dr. Karan Watson for providing critical feedback that strengthened the paper. The open access publishing fees for this article have been covered by the Texas A&M University Open Access to Knowledge Fund (OAKFund), supported by the University Libraries.

References

1. N. Al-Holou, N. M. Bilgutay, C. Corleto, J. T. Demel, R. Felder, K. Frair, J. E. Froyd, M. Hoit, J. Morgan and D. L. Wells, First-year integrated curricula: Design alternatives and examples, *Journal of Engineering Education*, **88**(4), pp. 435–448, 1999.
2. S. D. Fournier-Bonilla, K. L. Watson and C. Malavé, Quality planning in engineering education: Analysis of alternative implementations of a new first-year curriculum at Texas A&M University, *Journal of Engineering Education,* **89**(3), pp. 315–322, 2000.
3. B. M. Olds and R. L. Miller, The effect of a first-year integrated engineering curriculum on graduation rates and student satisfaction: A longitudinal study, *Journal of Engineering Education,* **93**, pp. 23–35, 2004.
4. N. A. Pendergrass, R. E. Kowalczyk, J. P. Dowd, R. N. Laoulache, W. Nelles, J. A. Golen and E. Fowler, Improving first-year engineering education, *Journal of Engineering Education,* **90**(1), pp. 33–41, 2001.
5. J. B. Urban and W. Trochim, The role of evaluation in research-practice integration: Working toward the ''golden spike,'' *American Journal of Evaluation,* **30**(4), pp. 538–553, 2009.
6. S. C. Funnell and P. J. Rogers, *Purposeful program theory: Effective use of theories of change and logic models*, Jossey-Bass/Wiley, San Francisco, 2001.
7. C. H. Weiss, *Evaluation research: Methods for assessing program effectiveness*, Prentice Hall, Englewood Cliffs, NJ, 1972.
8. C. H. Weiss, *Nothing as practical as good theory: Exploring theory-based evaluation for comprehensive community initiatives for children and families* in 'New Approaches to Evaluating Community Initiatives,' Aspen Institute, 1995.
9. C. H. Weiss, How can theory-based evaluation make greater headway?, *Evaluation Review,* **21**(4), pp. 501–524, 1997.
10. C. H. Weiss, Theory-based evaluation: past, present, and future, *New Directions for Evaluation*, **76**, pp. 41–55, 1997.
11. M. T. Holtzapple, K. Toback and C. Holtzapple, Foundation Coalition: Impact on chemical engineering education at Texas A&M University 20 years later, *Proceedings of the 6th First Year Engineering Experience (FYEE) Conference*, College Station, TX, USA, 2014.
12. M. C. Clark, J. E. Froyd, P. Merton and J. Richardson, Evolving models of curricular change: The experience of the Foundation Coalition, *Proceedings of the 110th American Society for Engineering Education Annual Conference & Exposition, Nashville, TN, USA*, 2003.
13. M. C. Clark, J. E. Froyd, P. Merton and J. Richardson, The evolution of curricular change models within the Foundation Coalition, *Journal of Engineering Education*, **93**(1), pp. 37–47, 2004.
14. D. Cordes, D. Evans, K. Frair and J. E. Froyd, The NSF Foundation Coalition: The first five tears, *Journal of Engineering Education,* **88**(1), pp. 73–77, 1999.
15. D. Barrow, B. Bassichis, D. DeBlassie, L. Everett, P. K. Imbrie and M. Whiteacre, An integrated freshman engineering curriculum, why you need it and how to design it, *Proceedings of the Frontiers in Education Conference, Atlanta, GA*, 1995.
16. S. D. Fournier-Bonilla, K. L. Watson, C. Malavé and J. E. Froyd, Managing curricular change in engineering at Texas A&M University, *International Journal of Engineering Education*, **17**(3), pp. 222–235, 2001.
17. J. E. Froyd and M. W. Ohland, Integrated engineering curricula, *Journal of Engineering Education*, **94**(1), pp. 147–164, 2005.
18. J. R. Morgan and R. W. Bolton, An integrated first-year engineering curricula, *Proceedings of the Frontier in Engineering Conference, Tempe, AZ, USA*, 1998.
19. H. T. Chen, *Theory-driven evaluations*, Sage, Thousand Oaks, CA, 1990.
20. P. J. Rogers, Using programme theory to evaluate complicated and complex aspects of interventions, *Evaluation*, **14**, pp. 29–48, 2008.
21. S. Y. Yoon, M. Cortez, P. K. Imbrie and T. Reed, A comparative study of student success between first-time-in-college and first-time-transfer engineering students, *International Journal of Engineering Education*, **34**(1), pp. 69–87, 2018.
22. S. Y. Yoon, P. K. Imbrie, T. Reed and K. J. Shryock, Identification of the engineering gateway subjects in the second-year engineering common curriculum, *International Journal of Engineering Education*, **35**(1A), pp. 232–251, 2019.
23. J. C. Richard, N. V. Mendoza Diaz, T. D. Wickliff and S. Y. Yoon, Enculturation of diverse students to the engineering practices through first-year engineering college experiences, *Proceedings of the 123rd American Society for Engineering Education Annual Conference and Exposition*, New Orleans, LA, USA, 2016.

24. J. Durlak and E. Dupre, Implementation matters: A review of research on the influence of implementation on program outcomes and the factors affecting implementation, *American Journal of Community Psychology*, **41**, pp. 327–350, 2008.
25. S. Scherer, C. P. Talley and J. E. Fife, How personal factors influence academic behavior and GPA in African American STEM students, *SAGE Open*, pp. 1–14, 2017.
26. J. Cohen, *Statistical power analysis for the behavioral sciences*, Lawrence Erlbaum, Hillsdale, NJ, 1988.
27. A. Field, *Discovering Statistics Using SPSS*, 3rd Ed., SAGE Publications Ltd., London, 2009.
28. J. Strobel and A. van Barneveld, When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms, *Interdisciplinary Journal of Problem-based Learning*, **3**(1), pp. 44–58, 2009.
29. C. L. S. Coryn, L. A. Noakes, C. D. Westine and D. C. Schröter, A systematic review of theory-driven evaluation practice from 1990 to 2009, *American Journal of Evaluation*, **32**(2), pp. 199–226, 2011.
30. J. D. Birckmayer and C. H. Weiss, Theory-based evaluation in practice: What do we learn?, *Education Review*, **24**(4), pp. 407–431, 2000.
31. M. A. Mansournia, M. Etminan, G. Danaei, J. Kaufman and G. Collins, Handling time varying confounding in observational research, *The BMJ, 359*, J4587, 2017.
32. S. Y. Yoon, M. T. Holtzapple and B. J. Dunbar, Longitudinal effects of the Foundation Coalition curriculum on chemical and petroleum engineering student performance, *Proceedings of the 124th American Society for Engineering Education Annual Conference and Exposition*, Columbus, OH, USA, 2017.

So Yoon Yoon is an assistant professor at the Department of Engineering Education in the College of Engineering and Applied Science (CEAS) at the University of Cincinnati. She received her PhD in Gifted Education, and an MSEd. in Research Methods and Measurement with a specialization in Educational Psychology, both from Purdue University. She also holds an MS in Astronomy and Astrophysics and a BS in Astronomy and Meteorology from Kyungpook National University, South Korea. Her work centers on engineering education research as a psychometrician, program evaluator, and data analyst, with research interests in spatial ability, creativity, engineering-integrated STEM education, and meta-analysis. As a psychometrician, she has revised, developed, and validated more than 10 instruments beneficial for STEM education practice and research. She has authored/co-authored more than 60 peer-reviewed journal articles and conference proceedings and served as a journal reviewer in engineering education, STEM education, and educational psychology. She has also served as a co-PI, an external evaluator, or an advisory board member on several NSF-funded projects.

Mark Thomas Holtzapple received his chemical engineering degrees from Cornell University (BS, 1978) and the University of Pennsylvania (PhD, 1981). After his formal education, he served as a captain in the US Army Natick R&D Center and worked on a miniature air conditioner for soldiers wearing chemical protective clothing. In 1986, he joined the faculty in the Department of Chemical Engineering at Texas A&M University. He has received many awards for teaching and research, including the Presidential Green Chemistry Challenge Award from the president and vice president of the United States. His research focuses on sustainability including conversion of waste biomass to fuels, chemicals, and animal feed; high-efficiency engines and air conditioners; conversion of waste heat to electricity; high-torque electric motors; and water desalination. During his career, he has taught nearly every core course in chemical engineering. For 25 years, he taught first-year engineering courses to students from all engineering disciplines. He co-authored *Foundations of Engineering*, a first-year engineering textbook suitable for all engineering disciplines.