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Identification of the Engineering Gateway Subjects in the Second-Year Engineering Common Curriculum*

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With increased improvements in retention after the first-year engineering (FYE) experience, the next largest hurdle is the second year, also known as sophomore slump, where there can be even larger losses than in the first-year. Considering attrition when students have an unsatisfactory grade in an engineering gateway course, poor performance in the gateway subjects may cause slump of the sophomores, resulting in many leaving engineering. This study attempted to identify engineering gateway courses as part of the seven second-year engineering (SYE) common subjects (i.e., Multivariate Calculus, Differential Equations, Statics/Dynamics, Materials, Solid Mechanics, Thermodynamics, and Electric Circuits), while providing a holistic view of engineering student performance in the SYE common subjects. At a southwest public university, course performance and graduation status of 1,581 engineering students who were admitted in 2006 and attempted to take at least one course of the seven SYE common subjects were tracked for 8.5 years. Descriptive statistics were applied to identify trends in students' performance in the common subjects and individual courses, followed by subgroup analyses using inferential statistics. Among the seven subjects, Multivariate Calculus was the engineering gateway subject with the highest failure rate, followed by Differential Equations and Statics/Dynamics. Materials had the lowest failure rate. Student performance varied by gender, race/ethnicity, residence, and admission type. As an exploratory study, the findings of this study will enable engineering faculty to consider ways to improve student performance in the SYE gateway subjects, which will hopefully ease sophomore slump and facilitate junior jump.

Keywords: sophomore engineering students; sophomore common subjects; engineering gateway courses

1. Introduction

Improving retention and graduation rates of engineering students is a pivotal strategy in national initiatives to increase the number of graduates while maintaining and improving the quality of engineers. The first year of undergraduate engineering programs, formerly one of the most infamous years for retention, has now been extensively researched [1]. With evidence-based programming implementations, many institutions have shown increased first-year retention rates as high as upper 80th/lower 90th percentages, increasing from upper 70th/lower 80th percentiles [2–4]. These improvements include changes in first-year engineering (FYE) key curricula, including Calculus [5, 6], Chemistry [7], Physics [8], and Engineering [9], as well as improvements in facilities to allow active and collaborative pedagogies [10], increased mentoring [11–12], and improved learning communities [13] and advising [14].

With increased improvements in addressing the FYE experience, the next largest hurdle with respect to retention is the second year, where there can be even larger losses than in the first year [4]. This next obstacle is the focus of this study. As shown in the systemic view on the progression of engineering students from prospect to graduate by Holloway et al. [15], student attrition has been occurring mostly in their first year, followed by sophomore year. Therefore, we consider the major processes to be recruiting, admission, and retention, thus illustrating that increasing the number of engineering professionals is not only a matter of recruitment but also a critical matter of retention in both first-year and the second-year programs.

Engineering students go through a transitional period during their second year, similar to the transition to college already experienced in their first year. It is during this second year that they most

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often begin their discipline specific engineering education. The issues of academic preparation, academic and social integration, faculty engagement, and financial burdens are still as relevant to sophomores as they are to first-year students [16]. Building on the existing interest to recruit, retain, and graduate engineering students and the multitude of efforts to enhance, improve, and expand the first-year experience to the capstone experience, this study solely focuses on the relationship between engineering students' performance in major sophomore courses and graduation outcomes.

1.1 Purpose of the study

The purpose of this study was to provide a holistic view of engineering student performance in the second-year engineering (SYE) common subjects, while identifying engineering gateway courses in the SYE subjects and exploring the relationship between student course performance and graduation outcomes. Here, the SYE common subjects at the institution were identified to be the foundational subjects, which are required for second-year curricula in most major engineering programs and contain high enrollment rates after completion of the FYE curriculum. Student graduation outcomes were evaluated using their graduation status in engineering, time-to-graduation, and cumulative GPA.

The following questions guided this study: (a) how do students perform in the SYE common subjects; (b) which are identified as engineering gateway subjects at the institution; (c) how do engineering students' demographic differences relate to variations in their academic performance in the SYE common subjects; and (d) how does engineering students' performance in the SYE common subjects relate to their overall graduation outcomes in terms of graduation status, time-to-graduation if graduating in engineering, and their cumulative GPA? Here, we aimed to closely investigate variations of the outcome variables in the relationship by students' demographic characteristics, such as gender, race/ethnicity, residence, and admission type (first-time in college [FTIC] versus first-time transfer [FTT]).

2. Background

2.1 Sophomore slump and junior jump

According to the literature and undergraduate retention experts, such as Hunter et al. [17] and Seidman [18], the second and third years (or "mid years") are sparsely researched. The general phenomenon that has been observed is a large drop in retention rates between the second to the third year (the sophomore slump). Retention rates then pick back up and are fairly solid from third to fourth year (the junior jump) and then moving forward to graduation by the sixth year. The first of these mid years is often referred to as the "Sophomore Slump" [19, 20] or "The Invisible Year" [21], which is a nearly 60 year-old phenomenon because of the significant number of dropouts or transfers during the second year. The literature on sophomore slumps revealed possible reasons for the phenomena based on the fact that many times students struggle with increased academic workload, are uncertain about a major, and possess a superficial commitment to their institution, which result in disengagement with an academic program [20, 22–24].

Following successful retention in the junior year, the emphasis shifts to discipline-specific knowledge and professional preparation, sometimes referred to as "Junior Jump." One of the key reasons for the Junior Jump is the changeover from general theoretical knowledge to discipline-specific knowledge and professional preparation [25]. Research on junior-year retention is sparse within the collegiate retention literature. To complicate the situation, there are multiple definitions of collegiate level junior-year retention. Within the literature, junior-year retention may be defined as third to fourth year retention or third year to graduation [18]. Seidman [18] also points out that a potential reason for the lack of scholarship is the high likelihood of matriculation once a student embarks upon their third year. As students experience the shift from theoretical knowledge to applied knowledge within the program of study, they often begin internships after completing the second year and begin to expand their professional networks. Offering juniors opportunities to apply their knowledge in real world situations, such as co-ops and internships, and to develop relationships with working engineers may be predictors of success. In sum, these sparsely researched middle years are critical not only to matriculate more engineering professionals but also to be integral to the engineering students' development.

2.2 Gateway courses

In education, "gateway courses", often referred to as "barrier courses" or "gatekeeper courses," are usually considered to meet the following criteria: (a) credit bearing courses as required by a program of study, (b) foundational level courses as an entry to a major, (c) courses with high enrollment as defined by the program, and (d) courses at high risk of failure grades (e.g., DFW—poor, fail, and withdraw) [26]. Fig. 1 shows student flow on potential outcomes by taking an engineering gateway course, which was modified from Andrade's [27, 28] (1999, 2001) flowchart to explore efficiency and effective-

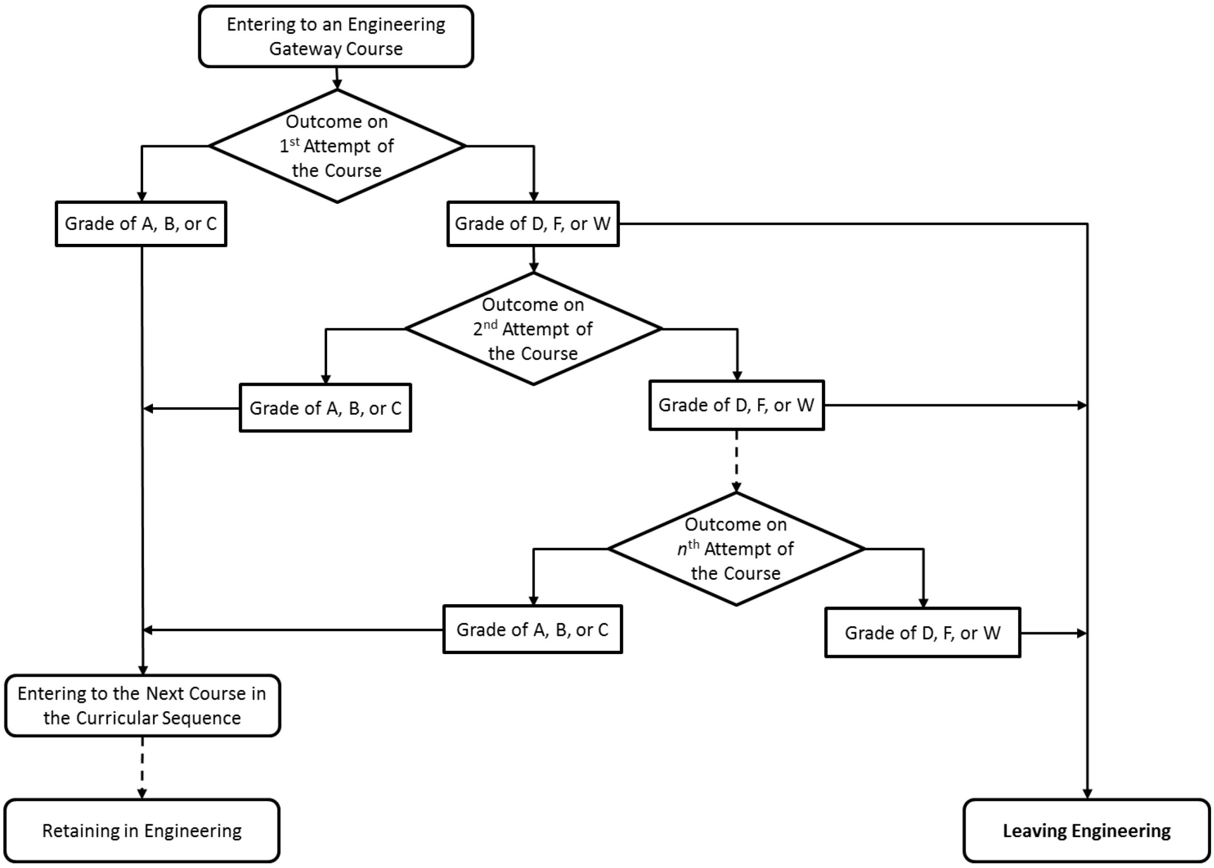

Fig. 1. Student flow on potential outcomes in taking an engineering gateway course modified from Andrade's [27, 28] figures.

ness of a gateway course with curricular reform. In detail, Andrade [27, 28] conceptualized the pass rate of first-time course attempts by students as an index of course efficiency (= the number of students who took the course for a first-time and passed the course / the number of students who took the course for a first-time; denoted as CEI-P hereafter) and the pass rate of the first-time course attempts by students who enrolled in the next course in the curriculum sequence as an index of course effectiveness (denoted as CEI-N hereafter). In addition, the average number of gateway course repetitions per student for passing was conceived to characterize student patterns in course taking, which serves as an additional indicator of course efficiency (= the total number of the same course repetitions by students / the total number of students; denoted as CEI-R hereafter). An index of 1.0 for all three indicators is ideal for a gateway course to be efficient and effective, and values less than 1.0 for the CEI-P and CEI-N and a value over 1.0 for the CEI-R indicate the need of improvement. This could include adjustments to instructional strategies and/or student achievement in the course.

Therefore, if students receive an unsatisfactory grade on an engineering gateway course as shown in Fig. 1, this can be one of the possible causes of attrition. Poor performance in the sophomore gateway courses may cause slump in the sophomores, resulting in students leaving engineering. In addition, other academic and nonacademic reasons may occur, such as demotivation, loss of sense of belonging, financial burden, and family issues [29, 30]. Therefore, it is evident that gateway courses in engineering are also critical for student success in engineering (i.e., graduation in engineering with relatively a short time period and a good GPA). In other words, student performance in an engineering gateway course might be strongly correlated with their retention in the program of study, time-to-graduation, and cumulative GPAs. Thus, there is a need to investigate the efficiency and effectiveness of gateway courses in engineering curricula to support engineering students' success.

2.3 Second-Year Engineering (SYE) common subjects

In most four year engineering curricula across the nation[1], second-year engineering (SYE) common subjects in engineering include advanced mathe-

[1] At some engineering programs, specific engineering courses are offered in the first-year engineering curriculum but most do not include subjects, such as multivariate calculus, thermodynamics, and electric circuits.

matics (i.e., Multivariate Calculus and Differential Equations) and engineering sciences (i.e., Statics/Dynamics[2], Materials, Solid Mechanics, Thermodynamics, and Electric Circuits), and student success in these subjects are prerequisites for progress in any engineering major (e.g., aerospace, biomedical, chemical, civil, environmental, mechanical, etc.). Therefore, the likelihood of student success and graduation is influenced by mastery of the course content and course outcomes in SYE common subjects. A common measure used to allow students to enroll in courses for which the SYE common subjects are a prerequisite is the obtainment of passing course grades.

While numerous initiatives have focused on improving student success in key courses in the FYE curricula [5–9], several initiatives have directed attention to enhancing student performance in key SYE common subjects in engineering. Nonetheless, as Montfort, Brown, and Pollock [31] pointed out, the literature revealed uneven focus on a few subjects, such as Statics [32–37] and Thermodynamics [38–41]. Comparatively, little attention have been paid to engineering students' learning in Materials [31, 42, 43], Solid Mechanics [44], and Electric Circuits [45, 46]. Furthermore, there has been a lack of obtaining a holistic view of engineering student performance across SYE common subjects, conducting rigorous studies on the implementation of research-based instructional strategies (RBIS), and evaluating the effects of RBIS on student performance in engineering science courses [47].

3. Methods

3.1 Setting

At a large southwest public university, engineering was the largest program with 12 departments that provided 19 different curriculum tracks as of 2006. Thirteen tracks from nine departments had an almost identical first-year engineering (FYE) curriculum that included mathematics (engineering mathematics [Calculus] I and II), chemistry (fundamentals of chemistry I and II or chemistry for engineers), physics (mechanics and electricity and optics), and engineering (foundations of engineering I and II) [48]. In the SYE curricula, there are more variations by program than the FYE curricula. However, as shown in Table 1, Multivariate Calculus, Statics/Dynamics, and Materials were the subjects commonly required in the first semester of the SYE curricula, and Differential Equations, Solid Mechanics, Thermodynamics, and Electric Circuits were the subjects commonly required in the second semester of the SYE curricula. Six curriculum tracks (Aerospace [AERO], Biological & Agricultural Engineering [BAEN], Civil Engineering [CVEN], Ocean Engineering [OCEN], Mechanical Engineering [MEEN], and Nuclear Engineering [NUEN]) required courses from all seven subjects in the SYE curricula. These six curriculum tracks comprised 45.5% of the total engineering undergraduate population in 2006. All but two tracks in engineering technology (ENTC-E and ENTC-T) required some subset of the seven courses, which comprised 52.4% of the total. In terms of subjects, Multivariate Calculus and Differential Equations were required in 15 curriculum tracks, and Statics/Dynamics and Materials were required in 10 curriculum tracks. Therefore, in this study, the seven subjects listed in Table 1 were identified to be the SYE common subjects at the university for engineering.

Note that several courses for the same subject were available based on the specific program, even though the content of the subject was typically quite similar across the courses. For example, the Department of Mathematics (MATH) offered three mathematics courses for engineering students: two courses for Multivariate Calculus (MATH1 and MATH2) and one course for Differential Equations (MATH3). The Department of Electrical Engineering (ELEN) offered two courses for Electric Circuits (ELEN1 and ELEN2). However, Statics/Dynamics courses were offered by four programs: AERO, CVEN, ENTC, and MEEN. Similarly, Materials courses were offered by five programs: AERO, CHEN, CVEN, ENTC, and MEEN. Therefore, eight programs (MATH, AERO, BAEN, BMEN CHEN, CVEN, ENTC, and ELEN) provided at least one course on the SYE common subjects. Even though engineering programs signified students to take the courses offered by their programs, the course credits from different programs were transferrable if the courses were on the same subjects.

3.2 Sample

The target population of this study was 2,271 newly admitted students who started their first semester in the summer or fall of 2006 in an engineering program at a large southwest public university. The 2006 cohort was chosen because at the time when we initiated this study, it was the most recent cohort that we were able to retrieve graduation outcomes after six years. We defined them as the 2006 cohort for the purpose of this study. Note that we treated the first-time transfer (FTT) students who entered the institution together with the first-time in college (FTIC) students as the target population of the same cohort based on the justification by Yoon et

[2] At this institution, statics and dynamics are combined in the same courses in the SYE curriculum. At other institutions, statics and dynamics can be taught in separate courses.

Table 1. Second-Year Engineering (SYE) Common Subjects by Engineering Curriculum Track in 2006

	First Semester			Second Semester			
Curriculum Track	**Multivariate Calculus**	**Statics/ Dynamics**	**Materials**	**Differential Equations**	**Solid Mechanics**	**Thermo-dynamics**	**Electric Circuits**
Aerospace Engr. (AERO)	MATH	AERO	AERO	MATH	AERO	AERO	ELEN
Biological & Agricultural Engr. (BAEN)	MATH	MEEN	MEEN	MATH	CVEN	BAEN	ELEN
Biomedical Engr. (BMEN)	MATH	–	–	MATH	BMEN	–	ELEN
Chemical Engr.(CHEN)	MATH	–	CHEN[b]	MATH	–	CHEN	–
Civil Engr. (CVEN)	MATH	CVEN	CVEN[a]	MATH	CVEN	MEEN[b,d]	ELEN[b,d]
Ocean Engr. (OCEN)	MATH	CVEN	CVEN[a]	MATH	CVEN	MEEN	ELEN
Computer Science (CPSC)	MATH	–	–	MATH [b]	–	–	–
Computer Engr. – Computer Science (CEEN)	MATH	–	–	MATH	–	–	ELEN
Computer Engr. – Electrical Engr. (ELEN-C)	MATH	–	–	MATH	–	–	ELEN
Electrical Engr. (ELEN-E)	MATH	–	–	MATH	–	–	ELEN
Electronics Engr. Technology (ENTC-E)	–	–	–	–	–	–	–
Telecommunications Engr. Technology (ENTC-T)	–	–	–	–	–	–	–
Manufacturing & Mechanical Engr. Technology (ENTC-M)	–	ENTC	ENTC	–	–	–	–
Industrial Distribution (IDIS)	–	–	ENTC	–	–	–	–
Industrial Engr. (INEN)	MATH	MEEN	MEEN	MATH	–	MEEN	ELEN
Mechanical Engr.(MEEN)	MATH	MEEN	MEEN	MATH	CVEN	MEEN	ELEN
Nuclear Engr.(NUEN)	MATH	MEEN	MEEN[b]	MATH	CVEN	MEEN	ELEN
Radiological Health Engr. (RHEN)	MATH	MEEN	–	MATH	CVEN[b]	MEEN	ELEN[b]
Petroleum Engr.(PETE)	MATH	MEEN	–	MATH	CVEN	MEEN	ELEN[c]
N. of Curriculum Tracks	15	10	10	15	9	10	13
No. of Courses	2	4	5	1	3	4	2

Note. Engr. = Engineering; "–" = Not Required.
[a] The subject course was required in the second semester of the sophomore curriculum; [b] The subject course was required in the junior curriculum; [c] The subject course was required in the senior curriculum; [d] Civil Engineering program required for students to take either Thermodynamics or Electric Circuits.

al. [49]. Among them, 1,581 students (69.6%) who registered for at least one course in the seven SYE common subjects were considered as participants of the study for analyses. Table 2 shows the demographic characteristics of the 2006 cohort students in this study. As Hispanic population has been growing in the state of the university, the proportion of Hispanic students in the participants of this study seemed to reflect such a trend.

Table 3 shows the number of students who attempted course credits for at least one course in the SYE common subjects at the institution. Here, courses are indicated by the name of a department that offered the courses. As expected, smaller percentages of students received transfer courses credits in the SYE common subjects than students did for the FYE common subjects [48, 49].

3.3 Procedure

The 2006 cohort students' course performance and graduation status in engineering were tracked for 8.5 years using data retrieved from the university archive. Therefore, the fall of 2014 semester showed the 2006 cohort students' last academic activities if there were any. Since there are several ways that students can achieve course credits, we categorized these course credits into two groups: credits from the university and transfer course credits from an institution other than the university. Course credits from the university were the first attempted credits for students who took a course in the SYE common subjects at the university. Note that students can take the same course multiple times until they pass the course or achieve a better grade. Here, grades of A, B, and C are passing grades, and D, F, W, and Q (DFWQ—poor, fail, withdraw, and Q-drop[3]) are considered failing grades at the university[4].

There are three possible forms of transfer course credits (credit by exam, transfer credits achieved from other institutions prior to enrollment at the university, and transfer credits achieved from other

[3] A student may drop a course with no record during school semesters with an approval of the student s dean or designee or department. The symbol Q is given to indicate a drop without penalty. Undergraduate students are normally permitted four Q-drops during their undergraduate studies.
[4] The university does not use plus and minus grades with A, B, C, and D.

Table 2. Demographic Characteristics of the 2006 Cohort Students and Participants of the Study

	2006 Cohort		**Participants**	
Category	***n***	**%**	***n***	**%**
Gender				
Female	474	20.9	315	19.9
Male	1,797	79.1	1,266	80.1
Residence				
Domestic	2,186	96.3	1,502	95.0
International	85	3.7	79	5.0
Race/Ethnicity[a]				
Hispanic	350	16.0	232	15.4
Asian	118	5.4	80	5.3
Black	76	3.5	41	2.7
White	1,604	73.4	1,121	74.6
Unspecified	4	0.2	1	0.1
Other Minorities[b]	34	1.6	27	1.8
Admission Type				
First-time in college (FTIC)	1,989	87.6	1,333	84.3
First-time transfer (FTT)	282	12.4	248	15.7
Entry Department				
Aerospace Engineering (AERO)	289	12.7	190	12.0
Biological and Agricultural Engineering (BAEN)[c]	34	1.5	19	1.2
Biomedical Engineering (BMEN)	145	6.4	106	6.7
Chemical Engineering (CHEN)	245	10.8	189	12.0
Civil Engineering (CVEN)	287	12.6	190	12.0
Computer Science (CPSC)	202	8.9	113	7.2
Electrical & Computer Engineering (ECEN)	237	10.4	148	9.4
Engineering Technology & Industrial Distribution (ETID)	107	4.7	78	4.9
Industrial & Systems Engineering (ISEN)	120	5.3	77	4.9
Mechanical Engineering (MEEN)	357	15.7	275	17.4
Nuclear Engineering (NUEN)	75	3.3	59	3.7
Petroleum Engineering (PETE)	173	7.6	137	8.7
Total	2,271	100.0	1,581	100.0

Note. [a] Race/Ethnicity was categorized for only domestic students; [b] Other Minorities included American Indian or Alaska Native, Native Hawaiian or other Pacific Islander, and Multiracial groups; [c] The BAEN program was housed in College of Agriculture and Life Sciences at the university but counted as an engineering program at the institution.

institutions after the enrollment at the university). Transfer credits using credit by exam were not observed in the data on SYE common courses. To understand their readiness/preparation for coursework in the SYE common subjects, we utilized the last transfer course credits if students achieved the credits prior to the enrollment at the university and the first transfer course credits if students achieved the credit after the enrollment at the university. The categorized grades were utilized for data analyses to explore the effects of SYE common courses on students' success and identify engineering gateway courses. Students' graduation status was categorized into one of three groups: graduation in engineering, graduation in non-engineering, and no graduation.

3.4 Data analyses

First, descriptive statistics were applied to identify trends in students' performance in the SYE common subjects and individual courses. Here, the two course efficiency indexes, CEI-P and CEI-R, were calculated for each course and subject. Note that the two indexes were characterized slightly different from Andrade's [27, 28] definitions where they were calculated for each subject. As Andrade [27, 28] defined the indexes for each course, the CEI-P for each subject was defined as the collectively calculated pass rate of students for all courses on the same subject when attempted for the first time by students. Similarly, the CEI-R for each subject was defined as the collectively calculated average number of the gateway course repetitions per student for all courses on the same subject. The reason for this is because even though 2006 cohort students started their engineering programs together, their academic semesters to achieve the credits for SYE common subjects were not consistent across students.

Second, to check statistically significant differences among subgroups (e.g., gender, race/ethnicity, residence, and admission type), inferential statistics, such as independent t-tests and one-way analysis of variances (ANOVAs), were applied for their final course grades. When multiple subgroup comparisons occurred for the same outcome, p-values for significance were adjusted to avoid the inflated Type I error. Note that the final course grades (letter grades) are an ordinal variable with rough quantitative sense of ordering

Table 3. Student Course Credit Records on the SYE Common Subjects at the Institution

Semester	Subject	Course	No. of Curriculum Tracks Required	Total *n*	%
First Semester	Multivariate Calculus[a]	MATH1	15	1,149	80.8
		MATH2	15	91	6.4
		Transferred	–	182	12.8
		Subtotal	15	1,422	100.0
	Statics/ Dynamics	AERO	1	121	11.5
		CVEN	2	226	21.5
		ENTC	1	58	5.5
		MEEN	6	629	59.9
		Transferred	–	16	1.5
		Subtotal	10	1,050	100.0
	Materials	AERO	1	119	11.8
		CHEN	1	116	11.5
		CVEN	2	209	20.8
		ENTC	2	188	18.7
		MEEN	4	365	36.2
		Transferred	–	10	1.0
		Subtotal	10	1,007	100.0
Second Semester	Differential Equations	MATH3	15	1,191	93.0
		Transferred	–	89	7.0
		Subtotal	15	1,280	100.0
	Solid Mechanics	AERO	1	103	13.2
		BMEN	1	58	7.5
		CVEN	7	611	78.5
		Transferred	–	6	0.8
		Subtotal	9	778	100.0
	Thermodynamics[b]	AERO	1	106	11.5
		BAEN	1	53	5.7
		CHEN	1	117	12.7
		MEEN	7	629	68.1
		Transferred	–	18	2.0
		Subtotal	10	923	100.0
	Electric Circuits[b]	ELEN1	13	233	28.3
		ELEN2	13	578	70.2
		Transferred	–	12	1.5
		Subtotal	13	823	100.0

Note. [a] Students can take either one; [b] Civil Engineering program required students to take either Thermodynamics or Electric Circuits.

but treated as an interval measure (i.e., A = 4, B = 3, C = 2, DFWQ = 1), similar to a Likert scale for mean comparisons. All assumptions for inferential statistics (e.g., independent observation, normality, and homogeneity of variance) were checked. In addition, effect sizes of mean differences among subgroups, such as Cohen's d and Partial η^2 were also calculated [50, 51]. Third, coefficients of the point-biserial correlation, which is the special case of the Pearson product moment correlations, were calculated to explore the relationship between grades on SYE common subjects (a continuous variable) and graduation status (a dichotomous variable) [51].

4. Results

4.1 Student performance in SYE common subjects/ courses

Fig. 2 shows overall distributions of student grades in the seven SYE common subjects as well as transfer course credits. Among the seven subjects, Multivariate Calculus was the subject with the highest DFWQ rate (21.4%), followed by Differential Equations (18.4%), Statics/Dynamics (18.3%), and Solid Mechanics (17.9%). Students had the lowest DFWQ rate (7.4%) in Materials. Students obtained the most transfer course credits in the Multivariate Calculus (12.8%), followed by Differential Equa-

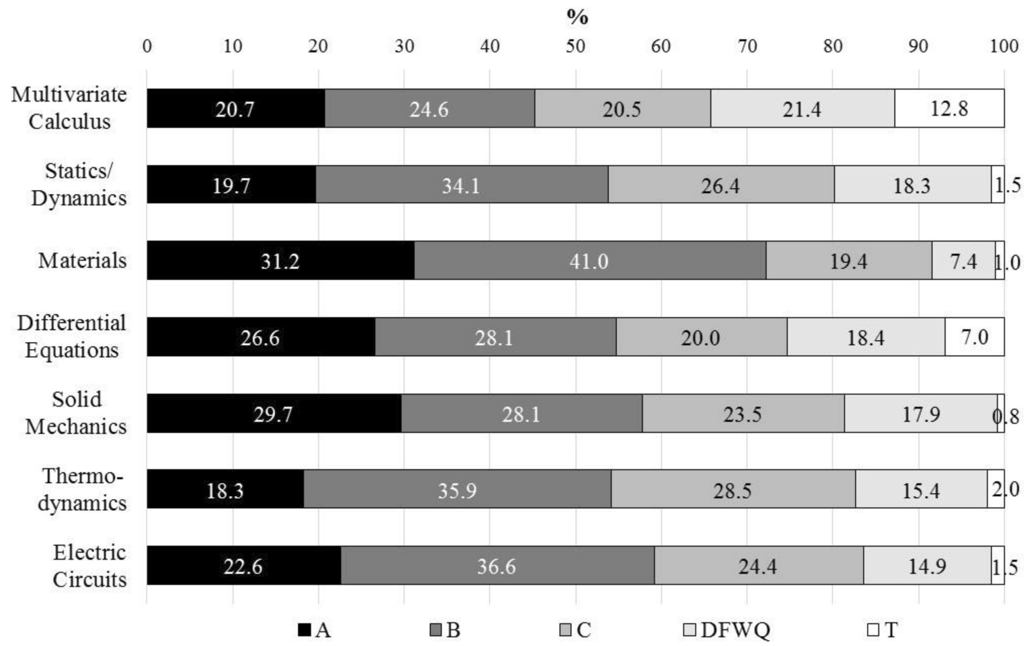

Fig. 2. Students' overall performance in the seven SYE common subjects.

tions (7.0%). A small percentage of students, ranging from 0.8% to 2.0%, achieved transfer course credits for the engineering science subjects in the SYE common subjects. The aggregated student performance in the seven SYE common subject courses were 24.1% A, 32.6% B, 23.3% C, and 16.2% D when considering courses attempted at the institution, and on average, 3.8% of the students had transfer credit records. However, among 1,581 students who attempted at least one SYE common course, 43.3% of the students (n = 684) received at least one grade of DFWQ in the seven SYE common subjects.

As several courses were available for a SYE common subject, student performance in each SYE common subject was disaggregated by course. Note that students who achieved transfer credits were not counted in the course level data analyses as we presented two course efficiency indexes, CEI-P and CEI-R. Fig. 3 shows a wide range of variations in student grades by course in the seven SYE common subjects.

While student grades tended to be evenly distributed, there was an apparent difference in DFWQ rates between two Multivariate Calculus courses (24.9% and 19.8% each). In Statics/Dynamics, while the course offered in MEEN showed the highest percentage of A (21.3%), the course offered in CVEN had the lowest percentage of A (16.8%) among the four courses. The course offered in AERO received the highest percentage of DFWQ (27.3%) while the course offered in ENTC showed the lowest percentage of DFWQ (12.1%). In Materials, the course offered in CHEN had the highest percentage of A (42.2%), while the course offered in AERO had the highest percentage of DFWQ (13.4%) among the five courses.

In Solid Mechanics, while the course offered in BMEN had the highest rate of A (72.4%) and the lowest DFWQ rate (5.2%), the course offered in CVEN had the highest DFWQ rate (20.1%) among the three courses. In Thermodynamics, the course offered in AERO showed the highest percentage of A (26.4%) and the lowest DFWQ rate (2.8%) among the four courses. The course offered in MEEN showed the lowest percentage of A (15.7%) and the highest percentage of DFWQ (19.6%). In Electric Circuits, even though the two courses were offered by the same program, we could observe an apparent difference in grade distributions (e.g., DFWQ rates of 8.6% and 17.8%).

Examining the findings differently using the course efficiency index of the pass rate (CEI-P) of first-time takers by SYE common subject, Multivariate Calculus had the lowest average CEI-P = 0.78, followed by Differential Equations with CEI-P = 0.80 and Statics/Dynamics with CEI-P = 0.81. Materials had the highest average CEI-P = 0.92 among the seven subjects, followed by Thermodynamics with CEI-P = 0.90, and Solid Mechanics and Electric Circuits each with CEI-P = 0.87. Regarding the average number of gateway course repetitions per student (i.e., CEI-R) by subject, the pattern was slightly different from the trends in the CEI-P. Multivariate Calculus had the highest average CEI-R = 1.22, followed by Differential Equations

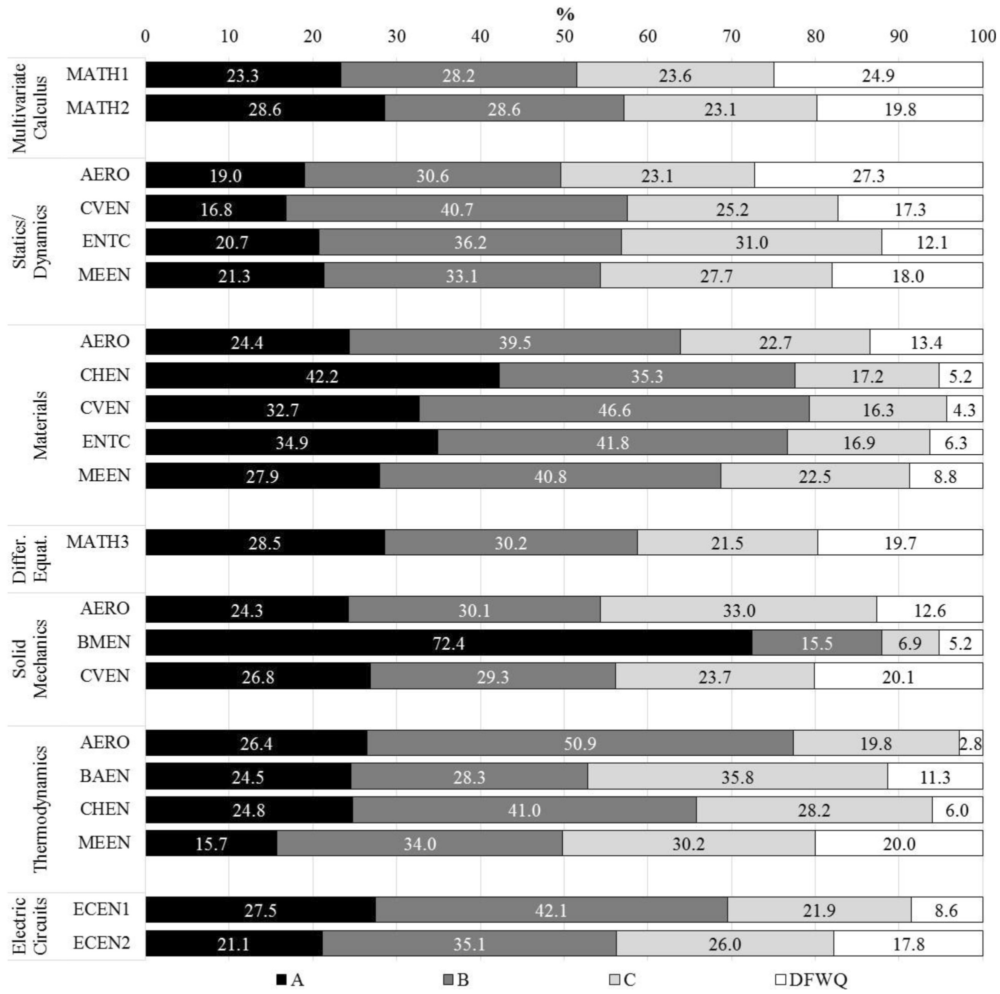

Fig. 3. Students' grade distribution on SYE common subjects by course offered by department.

with CEI-R = 1.19 and Solid Mechanics with CEI-R = 1.17. Materials had the lowest average CEI-R of 1.05 among the seven subjects, followed by Electric Circuits with CEI-R = 1.09, Thermodynamics with CEI-R = 1.10, and Statics/Dynamics with CEI-R = 1.12. Table 4 shows variations in the CEI-P and CEI-R in the courses within each SEY common subject. Note that several students took the same course multiple times, such as seven times for Differential Equations and five times for Solid Mechanics.

Fig. 4 displays the academic periods for which students attempted the SYE common courses. Regarding transfer credits, on average about 0.2% of FTIC students achieved transfer course credits in one of the seven SYE common subjects, and approximately 15% of FTT students achieved transfer course credits prior to enrolling in the university, which were mostly due to credits received in mathematics courses (41.6% for Multivariate Calculus and 28.3% for Differential Equations). When mathematics courses were excluded in the analyses, on average 6.7% of FTT and 1.0% of FTIC students received transfer course credits for the five engineering science courses in the SYE curricula. Regardless of their admission type, most students attempted SYE common courses between Fall 2006 and Fall 2010 for the first time at the institution, which is a wide range of four years. There were some outliers toward the right end of the distribution: in other words, a few students attempted courses for the first time at the institution eight years after enrolling. This data is not contained in Fig. 4. Note that some students, regardless of their admission type (i.e. FTIC or FTT), achieved transfer credits after their entrance to the institution.

Depending on the admission type and nature of the subjects, trends to attempt the courses differed slightly. While FTT students had a mode in Fall 2007, the FTIC students had a mode in Spring 2008, a one semester difference. As implied in Fig. 2, FTT students earned more transfer credits for advanced mathematics courses (i.e., Multivariate Calculus and Differential Equations) from other institutions

Table 4. Course Efficiency Indexes by Passing Rates and Course Repetitions at the Institution

Semester	Subject	Course	Total *n*	Average Grade	CEI-P	CEI-R	Max. No. of Course Repetitions	Academic Periods for the First-time Course
First Semester	Multivariate Calculus	MATH1	1,149	2.50	0.75	1.22	4	Fall 2006[a] – Fall 2010
		MATH2	91	2.66	0.80	1.19	3	Fall 2006 – Spr. 2009
	Statics/ Dynamics	AERO	121	2.41	0.73	1.19	2	Fall 2006 – Fall 2009
		CVEN	226	2.57	0.83	1.12	3	Fall 2006 – Fall 2010
		ENTC	58	2.66	0.88	1.14	3	Fall 2006 – Spr. 2012
		MEEN	629	2.58	0.82	1.10	4	Fall 2006 – Fall 2011
	Materials	AERO	119	2.75	0.87	1.09	4	Fall 2006 – Spr. 2010
		CHEN	116	3.15	0.95	1.05	2	Spr. 2007 – Spr. 2010
		CVEN	208	3.08	0.96	1.04	3	Fall 2006 – Spr. 2010
		ENTC	189	3.05	0.94	1.04	3	Fall 2006 – Fall 2012
		MEEN	365	2.88	0.91	1.05	2	Fall 2006 – Fall 2011[b]
Second Semester	Differential Equations	MATH	1,191	2.68	0.80	1.19	7	Fall 2006 – Fall 2013
	Solid Mechanics	AERO	103	2.66	0.87	1.15	3	Spr. 2007 – Fall 2010
		BMEN	58	3.55	0.95	1.07	3	Spr. 2007 – Spr. 2011
		CVEN	611	2.63	0.80	1.18	5	Fall 2006 – Spr. 2012
	Thermo-dynamics	AERO	106	3.01	0.97	1.01	2	Fall 2006 – Fall 2010
		BAEN	53	2.66	0.89	1.08	2	Spr. 2007 – Fall 2011
		CHEN	117	2.85	0.94	1.06	2	Fall 2006 – Spr. 2010
		MEEN	629	2.46	0.80	1.13	4	Fall 2006 – Fall 2012
	Electric Circuits	ELEN1	233	2.88	0.91	1.06	3	Fall 2006 – Spr. 2011
		ELEN2	578	2.60	0.82	1.11	3	Fall 2006 – Spr. 2012

Note. Average Grade: Course final letter grades were treated as an interval scale coded as A = 4, B = 3, C = 2, and DFWQ = 1 for calculation; CEI-P = Course efficiency index of the pass rate of first-time takers; CEI-R = Course efficient index calculated by the average number of the gateway course repetitions per student. [a] One student attempted to take the course in Fall 2005, and another student attempted to take the course in Spring 2006 from other programs; [b] Only one student took the course in Spring 2014.

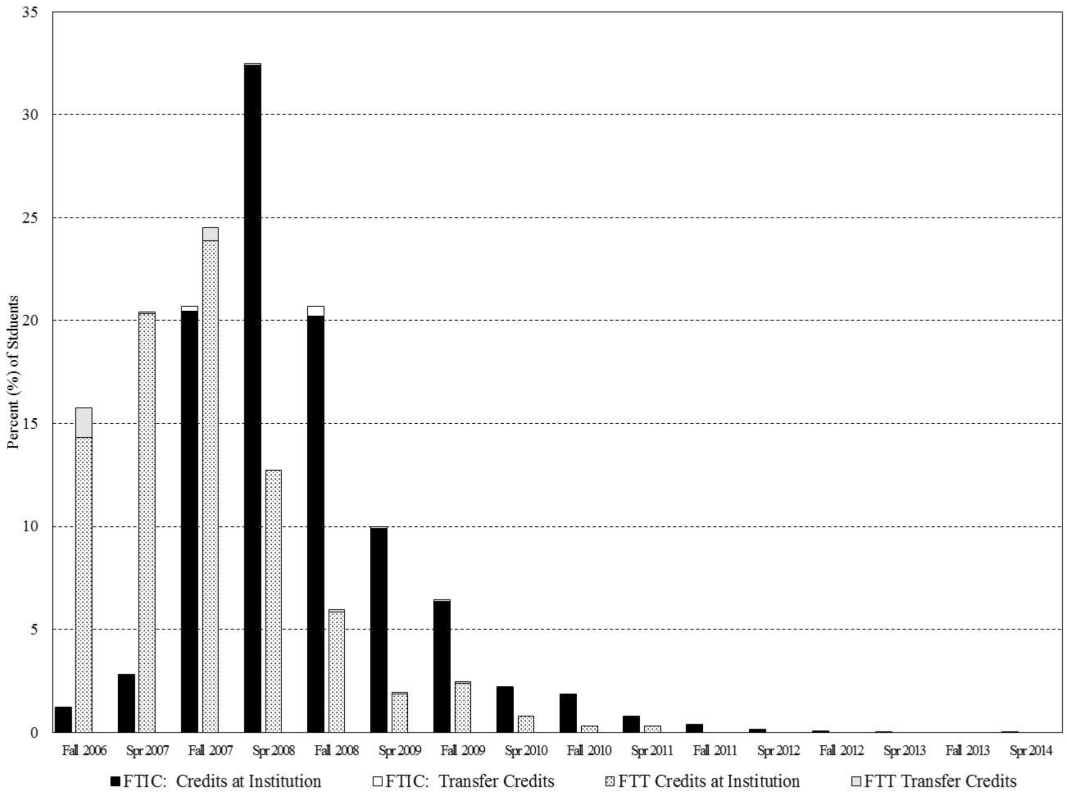

Fig. 4. Academic periods to take the SYE common courses (FTIC = First-time in college students; FTT = First-time transfer students).

prior to the enrollment at the university than FTIC students. However, not surprisingly there were no apparent differences in the transfer credits received in engineering science courses in the SYE curricula.

4.2 Identification of gateway courses in SYE common subjects

The comparisons among students' grades received in the seven SYE common subjects revealed that Multivariate Calculus had the lowest CEI-P and highest CEI-R, resulting in it being a gateway subject for students at the institution. Differential Equations followed next. Among the five engineering science subjects, Statics/Dynamics was the engineering gateway science subject for students, followed by Solid Mechanics. Since SYE common subjects are foundational with many of the courses having large class sizes, we attempted to identify gateway courses with the lowest CEI-P among the courses with the same subject at the institution. Therefore, the course offered by AERO in Statistics & Dynamics, the course offered by AERO in Materials, the course offered by CVEN in Solid Mechanics, the course offered by MEEN in Thermodynamics, and the second course offered by ECEN in Electric Circuits (i.e., ECEN2 in Fig. 3) were identified as engineering gateway courses at the institution.

4.3 Subgroup differences in student performance in SYE common subjects

Table 5 shows students' performance in the seven SYE common subjects by subgroups. Table 6 presents results from inferential statistical analyses, such as independent t-tests and one-way ANOVA about student performance in the seven SYE common subjects. These results varied by gender, race/ethnicity, residence, and admission type. Student performance by gender shows mixed results in the seven SYE common subjects. Female students performed better than male students in three subjects: Multivariate Calculus, Differential Equations, and Thermodynamics. The gender differences were all statistically significant, and the effect sizes of the differences in Cohen's d ranged from –0.21 to 0.02, which are small effects in magnitude. However, there were no significant gender differences in the other four subjects: Statics/Dynamics, Materials, Solid Mechanics, and Electric Circuits.

Because some racial groups (American Indian/Alaska Native, Native Hawaiian/other Pacific Islander, and multiracial students) did not have enough students for inferential statistical analyses, mean comparisons of the grades were applied for only four subgroups categorized as Hispanic, Asian, Black, and White. One-way ANOVAs revealed significant grade differences by race/ethnicity in

Table 5. Subgroup Performance on the SYE Common Subjects

Category	Multivariate Calculus			Statics/Dynamics			Materials			Differential Equations			Solid Mechanics			Thermo-dynamics			Electric Circuits		
	n	***M***	***SD***	***n***	***M***	***SD***	***n***	***M***	***SD***	***n***	***M***	***SD***	***n***	***M***	***SD***	***n***	***M***	***SD***	***n***	***M***	***SD***
Gender																					
Female	239	2.67	1.06	187	2.63	0.97	193	3.01	0.90	238	2.82	1.05	157	2.82	1.03	174	2.75	0.99	153	2.66	0.99
Male	1,001	2.47	1.11	848	2.55	1.02	804	2.96	0.90	953	2.64	1.10	615	2.67	1.09	731	2.54	0.95	658	2.68	0.99
Race/Ethnicity																					
Hispanic	175	2.15	1.08	151	2.21	1.03	154	2.70	0.92	169	2.43	1.13	90	2.48	1.15	120	2.31	0.96	118	2.35	0.97
Asian	67	2.40	1.09	43	2.42	1.01	41	2.83	0.80	67	2.72	1.07	30	2.53	1.17	38	2.55	1.06	47	2.53	1.06
Black	28	2.00	1.02	19	2.21	0.98	16	2.19	0.91	25	2.40	1.15	12	2.42	0.79	13	2.46	1.05	22	2.05	0.72
White	896	2.58	1.10	754	2.67	0.98	736	3.05	0.88	852	2.72	1.08	586	2.74	1.08	672	2.65	0.95	563	2.77	0.97
Residence																					
Domestic	1,185	2.49	1.10	986	2.56	1.01	964	2.97	0.90	1133	2.67	1.09	729	2.69	1.09	857	2.58	0.97	764	2.66	0.99
International	55	2.98	0.95	49	2.51	1.00	33	3.03	0.85	58	2.72	1.07	43	2.86	0.94	48	2.63	0.89	47	2.91	1.04
Admission Type																					
FTIC	1,129	2.55	1.10	896	2.58	1.02	843	2.96	0.91	1051	2.69	1.08	666	2.71	1.09	781	2.60	0.97	696	2.68	1.00
FTT	111	2.14	1.02	139	2.47	0.94	154	3.04	0.83	140	2.55	1.13	106	2.66	1.01	124	2.50	0.93	115	2.68	0.92

Note. FTIC = First-time-in college; FTT = First-time transfer; Course final letter grades were treated as an interval scale coded as A = 4, B = 3, C = 2, and DFWQ = 1.

Table 6. Inferential Statistics about Subgroup Differences in Student Performance

Category	Subject	*t or F*	*df*	*p*	*ES*
Gender (Male vs. Female)	Multivariate Calculus	–2.47	1238	0.014	Cohen's d = –0.18
	Statics/Dynamics	–1.00	1033	0.343	Cohen's d = –0.08
	Materials	–0.57	995	0.477	Cohen's d = –0.06
	Differential Equations	–2.34[a]	378.01	0.020	Cohen's d = –0.17
	Solid Mechanics	–1.47	770	0.142	Cohen's d = –0.14
	Thermodynamics	–2.47	903	0.013	Cohen's d = –0.21
	Electric Circuits	0.25	809	0.803	Cohen's d = 0.02
Race/Ethnicity (Among Hispanic, Asian, Black, and White)	Multivariate Calculus	9.76	3, 1162	<0.001	Partial η^2 = 0.025
	Statics/Dynamics	10.44	3, 963	<0.001	Partial η^2 = 0.031
	Materials	11.36	3, 943	<0.001	Partial η^2 = 0.035
	Differential Equations	3.97	3, 1109	0.008	Partial η^2 = 0.011
	Solid Mechanics	2.05	3, 714	0.106	Partial η^2 = 0.009
	Thermodynamics	4.36	3, 839	0.005	Partial η^2 = 0.015
	Electric Circuits	9.78	3, 746	<0.001	Partial η^2 = 0.038
Residence (International vs. Domestic)	Multivariate Calculus	–3.72[a]	60.94	<0.001	Cohen's d = 0.45
	Statics/Dynamics	0.40	1033	0.711	Cohen's d = –0.02
	Materials	–0.78	995	0.691	Cohen's d = 0.13
	Differential Equations	–0.35	1189	0.730	Cohen's d = 0.05
	Solid Mechanics	–1.13[a]	48.88	0.266	Cohen's d = 0.16
	Thermodynamics	–0.07	903	0.759	Cohen's d = 0.01
	Electric Circuits	–1.69	809	0.091	Cohen's d = 0.25
Admission Type (FTIC vs. FTT)	Multivariate Calculus	4.03	136.5	<0.001	Cohen's d = 0.38
	Statics/Dynamics	1.03	1033	0.272	Cohen's d = 0.09
	Materials	–1.20	995	0.294	Cohen's d = –0.10
	Differential Equations	1.46	1189	0.145	Cohen's d = 0.13
	Solid Mechanics	0.43	770	0.669	Cohen's d = 0.05
	Thermodynamics	0.96	903	0.300	Cohen's d = 0.09
	Electric Circuits	0.00	809	0.999	Cohen's d = 0.00

Note. [a] Due to unequal variances between two subgroups, Levene's t-test was conducted; *ES* = Effect size.

the SYE common subjects except Solid Mechanics. Post-hoc analyses using Bonferroni tests revealed that White students performed better than Hispanic and Black students in Multivariate Calculus, Statics/Dynamics, Materials, and Electric Circuits. In addition, White students showed better performance than Hispanic students in Differential Equations and Thermodynamics. Asian students displayed better performance than Black students only in Materials.

The significant grade differences between Domestic and International students existed only in Multivariate Calculus; international students performed better than domestic students, and the difference was moderate with Cohen's d = 0.45. Similarly, FTIC students performed better than FTT students only in Multivariate Calculus, and the effect size of the difference was moderate with Cohen's d = 0.38. No significant differences existed in the other six SYE common subjects by residence and admission type.

4.4 Association of student performance with graduation outcomes

When students' graduation status was explored by grades received when the courses were attempted for the first-time for the seven SYE common subjects, slight differences existed in their graduation status by subject as shown in Table 7. Among the seven SYE common subjects, students who enrolled in Electric Circuits showed the highest graduation rate in engineering (94.5%), followed by Solid Mechanics (93.4%) and Thermodynamics (93.2%), which were usually recommended to be taken in the second semester of the second year curricula. Conversely, students who attempted Multivariate Calculus showed the lowest graduation rate in engineering (79.5%), followed by Differential Equations (85.0%) and Statics/Dynamics (89.2%). Interestingly, students who received a DFWQ in Materials showed the lowest graduation rate in engineering (54.8%), followed by Multivariate Calculus (58.9%), Statics/Dynamics (65.4%), and Differential Equations (68.9%).

On average, students who achieved an A or B in the subjects showed high graduation rates in engineering, which were above 95%. Similarly, students who earned a C showed high graduation rates in engineering at 90.1%. Only 87.8% of students who earned transfer credits graduated in engineering. Students who received a DFWQ in their first attempt had a 73.3% graduation rate in engineering. Students who received a DFWQ at other institutions (i.e., TDFWQ), which was their last credit earned, prior to enrolling in the university or first credit from other institutions while they were

Table 7. Graduation status (%) by student performance in the seven SYE common subjects

Course	Grade	*n*	Graduation in Engineering (%)	Graduation in Non-engineering (%)	No Graduation (%)
Multivariate Calculus	A	294	91.2	5.1	3.7
	B	350	88.9	5.4	5.7
	C	292	82.9	9.9	7.2
	T	160	72.5	9.4	18.1
	DFWQ	304	58.9	19.1	22.0
	TDFWQ	15	60.0	13.3	26.7
	Total	1,415	79.5	9.8	10.7
Statics	A	207	95.7	1.9	2.4
	B	359	96.7	1.1	2.2
	C	277	91.7	3.2	5.1
	T	15	73.3	6.7	20.0
	DFWQ	188	65.4	10.1	24.5
	TDFWQ	0	0.0	0.0	0.0
	Total	1,046	89.2	3.5	7.3
Materials	A	314	98.4	0.3	1.3
	B	412	93.4	2.7	3.9
	C	196	86.2	3.6	10.2
	T	10	80.0	0.0	20.0
	DFWQ	73	54.8	16.4	28.8
	TDFWQ	0	0.0	0.0	0.0
	Total	1,005	90.6	3.1	6.3
Differential Equations	A	340	94.1	3.5	2.4
	B	360	91.1	5.6	3.3
	C	256	83.6	7.0	9.4
	T	85	75.3	8.2	16.5
	DFWQ	235	68.9	11.9	19.1
	TDFWQ	4	0.0	0.0	100.0
	Total	1,280	85.0	6.6	8.4
Solid Mechanics	A	231	97.4	0.9	1.7
	B	219	99.1	0.5	0.5
	C	183	95.1	1.6	3.3
	T	6	83.3	0.0	16.7
	DFWQ	139	76.3	8.6	15.1
	TDFWQ	0	0.0	0.0	0.0
	Total	778	93.4	2.3	4.2
Thermo-dynamics	A	168	98.2	0.0	1.8
	B	332	97.6	0.6	1.8
	C	264	95.5	0.8	3.8
	T	18	77.8	0.0	22.2
	DFWQ	139	74.1	7.9	18.0
	TDFWQ	0	0.0	0.0	0.0
	Total	921	93.2	1.6	5.2
Electric Circuits	A	186	96.8	2.2	1.1
	B	301	98.0	0.7	1.3
	C	201	95.5	2.0	2.5
	T	12	100.0	0.0	0.0
	DFWQ	123	80.5	3.3	16.3
	TDFWQ	0	0.0	0.0	0.0
	Total	823	94.5	1.7	3.8

Note. TDFWQ: Transferred grades that students who received a DFWQ at other institutions.

attending the university, showed the lowest graduation rate at 30.0%. Note that students who received a TDFWQ in Differential Equations were not able to graduate from engineering.

Table 8 shows correlations among student characteristics, performance in the seven SYE common subjects, and graduation outcomes. The correlation table presents similar results shown in the subgroup

Table 8. Correlations among student characteristics, performance in the SYE common subjects, and graduation outcomes

ID	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Gender	1.000	–	–	–	0.108*	–0.123*	–0.070*	–0.030	–0.023	–0.066*	–0.053	–0.083*	0.009
2	Residence	–	1.000	–	–	0.150*	–0.002	–0.092*	0.012	–0.013	–0.010	–0.036	–0.010	–0.059
3	Admission Type	–	–	1.000	–	0.449*	0.071*	0.107*	0.034	–0.033	0.042	0.015	0.035	0.000
4	Engineering Major	–	–	–	1.000	–	0.439*	0.290*	0.308*	0.334*	0.253*	0.264*	0.254*	0.199*
5	Time-to-Graduation	1,266	1,266	1,266	1,266	1.000	–0.415*	–0.292*	–0.250*	–0.198*	–0.230*	–0.291*	–0.233*	–0.274*
6	Cumulative GPA	1,581	1,581	1,581	1,581	1,266	1.000	0.599*	0.642*	0.567*	0.585*	0.664*	0.687*	0.689*
7	Multivariate Calculus	1,240	1,240	1,240	1,240	1,000	1,240	1.000	0.469*	0.317*	0.459*	0.407*	0.440*	0.437*
8	Statics/Dynamics	1,035	1,035	1,035	1,035	924	1,035	906	1.000	0.451*	0.396*	0.487*	0.457*	0.493*
9	Materials	997	997	997	997	904	997	752	829	1.000	0.342*	0.410*	0.445*	0.449*
10	Differential Equations	1,191	1,191	1,191	1,191	1,024	1,191	1,085	928	767	1.000	0.430*	0.468*	0.491*
11	Solid Mechanics	772	772	772	772	722	772	697	703	569	736	1.000	0.538*	0.506*
12	Thermo-dynamics	905	905	905	905	845	905	821	862	758	866	695	1.000	0.533*
13	Electric Circuits	811	811	811	811	766	811	724	626	486	770	553	607	1.000

Note. Gender (1= Male, 0 = Female); Residence (1 = Domestic, 0= International); Admission Type (1 = FTIC, 0 = FTT), Engineering Major (1 = Yes, 0 = No); "–" = Not applicable as correlation coefficients were not calculated; Time-to-Graduation is in the unit of semesters taken for graduation; Correlation coefficients are in the upper diagonal of the table and the sample sizes for correlations are in the lower diagonal of the table. * $p < 0.05$.

analyses section. Negative point-biserial correlation coefficients between gender and the course grades in six SYE common subjects except Electric Circuits indicated that female students tended to perform better than male students, but the correlations were only significant in Multivariate Calculus, Differential Equations, and Thermodynamics. However, all effect sizes were small. Regarding residence, the negative correlation with Multivariate Calculus, which is statistically significant, indicated that international students tended to perform better than domestic students. However, the correlation of residence with Differential Equations was not significant.

Cumulative GPA was negatively correlated with gender, implying better performance of female students than male students, which implies shorter time-to-graduation of female students at the institution with a high cumulative GPA. Point-biserial correlation coefficients between students' course grades in the six SYE common subjects and student graduation status in engineering were all positive and statistically significant. Even though the effect sizes were small, among the seven subjects, the correlation with grades in Materials was the largest (n = 997, r = 0.334, $p < 0.05$), closely followed by correlations with Statics/Dynamics (n = 1,035, r = 0.308, $p < 0.05$) and Multivariate Calculus (n = 1,240, r = 0.290, $p < 0.05$).

The correlation coefficients between students' course grades in the seven SYE common subjects and their time-to-graduation in engineering in terms of semesters taken for graduation were all negative but statistically significant. The effect sizes were small to moderate and comparable to the effect sizes from the correlation between course grades and graduation in engineering. Among the seven subjects, the correlation with Multivariate Calculus (n = 1,000, r = –0.292, $p < 0.05$) was negatively the largest, closely followed by Solid Mechanics (n = 722, r = –0.291, $p < 0.05$) and Electric Circuits (n = 766, r = –0.274, $p < 0.05$).

5. Discussion

To promote student success in engineering at the sophomore level, we attempted to diagnose the status of student performance in the SYE common subjects/courses in depth, identify gateway subjects/courses, and reveal the associations between student performance in the SYE common subjects and graduation outcomes at a large southwest public university. Further details on each finding are discussed below.

5.1 Student performance and identification of gateway subjects/courses

To identify engineering gateway courses, we utilized the course grades as a major indicator among the four criteria in this study because the other three criteria (i.e., (a) credit bearing courses as required by a program of study, (b) foundational level courses as an entry to major, and (c) courses with high enrollment as defined by the program) met the qualifications as the courses covered the SYE common subjects. Overall, we observed three apparent trends in students' performance in the SYE common subjects/courses.

First, advanced mathematics, such as Multivariate Calculus and Differential Equations were the gateway subjects with the highest failure rates and course repetitions per student. Among engineering science courses, Statics/Dynamics, offered typically in the first semester in the SYE, was the gateway subject followed by Solid Mechanics, offered in the second semester of the SYE curricula. As expected, the course efficiency indexes, CEI-P and CEI-R, were improved from the ones in the FYE common courses as the participants of this study had mostly completed the FYE curriculum [49]. In detail, while the averages of CEI-P and CEI-R on the FYE common courses were each 0.75 and 1.18, they were 0.87 and 1.11 in the SYE common courses. However, similar to the literature about FYE students' struggle in Calculus courses [49, 52, 53], this study presented that advanced mathematics courses (i.e., Multivariate Calculus and Differential Equations) had high failure rates at the sophomore level, too. Particularly, the fact that 43.3% of students experienced a failure in at least one or more of the seven SYE common subjects is alarming.

As suggested by Andrade [27, 28], high pass rates can be interpreted as the results of lowered academic standards or reflection of good/coherent curriculum and/or instructional strategies. Conversely, high failure rates can be the result of (a) high academic standards, (b) reflection of incoherent curriculum and/or (c) poor instructional strategies [27], along with a possibility of the difficulty inherent to a subject itself. Therefore, considering the impact of performance in mathematics and engineering science courses on students' achievement in subsequent engineering courses and persistence in engineering [54, 55], the findings of this study suggest the need of an institutional effort to improve student performance in the SYE gateway subjects.

For example, programmatic support to comprehensively review each sophomore course annually with the intent to reduce failure rates is ideal. If faculty have little experience in evaluating their courses, then the indexes, such as CEI-P, CEI-R, and CEI-N, can serve as means to show course efficiency, effectiveness, and cost-efficiency for students and departments [28]. Particularly, as the first semester performance influences students' decision for retention next semester, a strategic focus to improve student performance in Multivariate Calculus and Statics/Dynamics is critical. As the mathematics courses at the institution are offered by the mathematics department, programmatic strategies are necessary in collaboration with the two colleges (i.e., engineering and mathematics), such as curricular reform, tutoring, and/or a summer bridge program [56].

Second, student grade distributions were not even across SYE common courses in the same subjects. We observed a wide range of variations in student grades across the courses in the seven SYE common subjects related to engineering. Possible explanations for this phenomena could be because of the variations in (a) learning goals of a course for the same subject due to different focuses on content by program; (b) instructional strategies and assessment methods across semesters, considering that the same cohort student did not take the SYE common courses at the same time; and (c) student ability by program due to different criteria to accept students into the departments.

Even though students in each major are directed to take the courses offered by their particular engineering department if offered, the credits from courses on the same subjects offered by other departments are transferrable and equivalent. Therefore, departments and faculty need to be aware of the current variations in student outcomes across courses on the same subject and across semesters, so they can maintain consistency with rigor in the application of instructional and assessment methods for students.

Third, while students achieved more transfer course credits in the FYE common subjects as expected [49], they tended to directly earn more course credits from the institution in the SYE common subjects. The trends to transfer more course credits in mathematics subjects rather than engineering science subjects were similar for both FYE and SYE subjects. On the other hand, the proportions of transfer course credits became reduced at the sophomore level. Particularly, FTT students earned more transfer course credits in the advanced mathematics, but the majority of FTT students (more than 93%) tended to take engineering science courses in the SYE curricula at the institution. This is of course expected as it is difficult to find equivalent courses for the engineering science courses in the SYE curricula at two-year institutions where most transfer credits are received.

According to the policy for transfer students to be admitted to the institution, students must have at least a 2.5 GPA on a minimum of 24 credit hours of transferable coursework [49]. However, this criterion does not mean that the transferred coursework is equivalent to the coursework for the FYE curricula and beyond. As shown in Fig. 4, FTT students tended to attempt SYE common courses about one semester earlier than FTIC students. However, the distribution of the academic periods to take SYE common courses by FTT students seems to be hard to differentiate from the distribution by FTIC students. Therefore, analyzing FTT students' performance differently from FTIC students, simply because of the number of transfer credits that FTT students have earned, may not be justified.

5.2 Subgroup differences in student performance

When students were grouped by gender, race/ethnicity, residence, and admission type, several interesting trends existed in subgroup variations in student performance in the SYE common subjects (See Tables 5 and 6). First, on average female students' performance were comparable to or outperforming male students' performance in SYE common subjects. Second, White students at the institution tended to perform better than other racial/ethnic groups, which were Hispanic, Asian, and Black students in this study. According to the model minority stereotype [57, 58], Asian American students are expected to outperform other racial/ethnic groups in academic achievement. However, this expectation was not true in this study, which is a similar finding by Trytten, Lowe, and Walden [59]; they revealed no significant differences in GPAs among minorities in engineering.

Third, there were no significant differences in most SYE common subjects by residence. International students performed better than domestic students only in Multivariate Calculus, and the trend disappeared in Differential Equations. Fourth, FTT students' performance in the SYE common subjects were comparable to FTIC students except in Multivariate Calculus; FTIC students performed better than FTT students only in Multivariate Calculus. Fifth, interestingly, Multivariate Calculus was the course most pronounced with subgroup differences, ranging from small to medium magnitudes in all aspects by gender, race/ethnicity, residence, and admission type. Considering that Multivariate Calculus is the subject required in the most curriculum tracks as shown in Table 1, there is a dire need to examine this phenomenon, whether or not the subgroup differences in student performance on Multivariate Calculus are real subgroup characteristics after controlling individual differences in the abilities. If the subgroup differences still exist regardless of individual differences, then further efforts at the institutional or program level would be recommended to strategically support students in underperforming subgroups and reduce the gap.

5.3 Associations with graduation outcomes

As shown in Table 7 regarding student performance in their first attempted course in each subject, it was apparent that students who received a passing grade in a SYE common course tended to graduate in engineering. On one hand, if students received a DFWQ in their first attempt, one third of students were inclined to leave engineering in the end. On the other hand, two thirds of the students seemed to be resilient by repeating the course until they passed or switched to another engineering major that did not require the course, so they could stay in engineering. Interestingly, while Materials was the course with the highest rates of passing grades at the institution, students who failed Materials in their first attempt tended to leave engineering with the highest rate among the SYE common subjects. In other words, a failing grade in Materials can be an indicator or a red flag of a student with high risk of leaving engineering. Therefore, the findings of this study can increase academic advisor's awareness of the warning signal, so they can provide individualized support for struggling students at the earliest time possible.

The correlation matrix shown in Table 6 revealed the significant associations between student performance in the seven SYE common subjects and graduation outcomes in terms of graduation status, time-to-graduation in engineering, and the cumulative GPAs. Moderate magnitudes of correlations, which were all significant, existed among the seven SYE common course grades. All graduation outcomes were significantly correlated with students' grades in the seven SYE common subjects.

5.4 Limitations and future directions for research

Several points could be considered as limitations of this study. First, as an exploratory study, we considered SYE common courses required in most curriculum tracks with high enrollment rates at the institution for analyses. These conditions indicate that engineering gateway courses identified in this study can differ by the engineering program or institution. Therefore, replicated studies are necessary to understand student performance at the SYE curriculum level at other institutions with different student demographics and educational settings.

Second, even though we tracked student performance in the same cohort, students did not take the SYE common subjects/courses at the same time. In other words, we could not control the influence of external factors, such as instructional strategies, curriculum changes, and assessment methods for grades on student performance in the same SYE common subjects/courses. Even though it is common for the same instructors to teach a course for several semesters and/or there is consistency in the course curriculum across years, multiyear examination will reveal whether or not the findings of this study are unique to this cohort or generalizable across years at the institution.

Third, as a series of longitudinal study [60, 61] revealed significant factors, such as motivation, personality, and learning styles, which were influential on student performance in an introductory sophomore chemical engineering course, there is a need to explore nonacademic factors that may affect students' performance in the SYE gateway courses at the institution. For example, Holloway [4] found that engineering sophomores at a major Midwestern university were less engaged in learning and with faculty and advisors. In addition, sophomore women were more likely to be involved in engineering extracurricular activities than men, especially peer mentoring opportunities. The most significant predictor of overall satisfaction and intention to persist and graduate was satisfaction with peers on campus and surety of major choice. Gender-based differences may inform strategies to encourage men's involvement in extracurricular activities and the creation of classroom strategies that particularly encourage participation from women. Predictors of success outcomes for engineering sophomores point to the interconnectedness of experiences with faculty, advisors, and peers with individual student traits and characteristics.

Fourth, gateway course effectiveness as an index of course effectiveness (CEI-N), defined as students' success in the next course (i.e., the pass rate of the first-time takers who enrolled in the next course in the curriculum sequence; [28]), were not calculated in this study. As the SYE common courses are still foundational, several courses are possible for the subsequent course sequence. In other words, several CEI-Ns can be calculated for each SYE common course, but this analysis seems to be beyond the scope of this study due to the complexity of tracking individual students. A future study focusing on the effectiveness of SYE common courses on the next level courses can be completed by the engineering program.

Fifth, individual differences prior to taking the SYE common courses were not controlled in the course performance in the subgroup analyses. Therefore, to explore independent subgroup characteristics that may be influential in student performance, there is a need to examine subgroup differences after controlling individual differences, such as prerequisite course performance and academic aptitude reflected in SAT/ACT scores. In addition, the effects of intersectionality of gender and racial/ethnic differences in the SYE course performance would be an area for future research.

5.5 Significance of the study

Several points make this study significant to the engineering education community. First, this is the first attempt to systematically explore student performance on SYE common courses and identify engineering gateway subjects/courses at the sophomore curriculum level. Therefore, this study can serve as an exemplary research to identify engineering gateway subjects/courses at other institutions. Second, as we identified room for improvement in the engineering gateway subjects/courses at the institution, the findings of this study will enable engineering faculty, particularly those teaching gateway subjects/courses with high failure rates, to consider a curricular reform and possible changes in instructional methods to assist students with improving course performance. These changes will hopefully result in the students being retained after the sophomore year and achieving further successful student outcomes in terms of shorter time-to-graduation, higher cumulative GPAs, and better graduation rates in engineering.

> "The function of a gateway course should be that of a pump or springboard: to motivate and prepare entering students to succeed in the curricular sequence, thus increasing both the number and quality of students who will major in and graduate from the institution's academic programs" [28, p. 2].

By now focusing on the "mid years" or the sophomore and junior year of the curriculum, retention and graduation rates can be further improved. The sophomore year can no longer maintain the nickname of "The Invisible Year." With application of findings from this study, institutions will be able to incorporate appropriate applied knowledge and professional skills into the sophomore engineering courses and maintain this strong presence in the junior-year programming. Furthermore, as Faulkner [62] identified mismatches in the use of Calculus concepts between Statics and Circuits, a focus on middle years would allow horizontal and vertical changes in engineering curricula with coherent alignment of course contents by subject within the same student levels and across the student levels (i.e., freshman, sophomore, junior, and senior).

6. Conclusions

Since 2015, there have been continuous efforts to improve undergraduate engineering education at the department level nationwide in the United States. Support from NSF with the RED (REvolutionizing engineering and computer science Departments) program is one such example. Building upon successes in the first and capstone years, awardees in this program seek to improve the entire undergraduate experience by including changes to help improve the middle years as well. We believe that the analyses to identify second-year engineering gateway subjects presented in this study would serve as groundwork for benchmarking for other institutions, so the efforts to improve sophomore education would lessen engineering students' sophomore slump, facilitating their continuous success to boost their junior jump.

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