2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32713

Exploring the Relationship Between Matriculation Model and Time to Enrollment in Engineering Graduation Major

Baker A. Martin, Clemson University

Baker Martin is a Ph.D. Candidate in the Department of Engineering and Science Education at Clemson University and teaches in the General Engineering Program as part of the first-year engineering curriculum. His research interests include choice and decision making, especially relating to first-year engineering students' major selection. He earned his BS from Virginia Tech and his MS from The University of Tennessee, Knoxville, both in chemical engineering.

Dr. Marisa K. Orr, Clemson University

Marisa K. Orr is an Assistant Professor in Engineering and Science Education with a joint appointment in the Department of Mechanical Engineering at Clemson University. Her research interests include student persistence and pathways in engineering, gender equity, diversity, and academic policy. Dr. Orr is a recipient of the NSF CAREER Award for her research entitled, "Empowering Students to be Adaptive Decision-Makers."

©American Society for Engineering Education, 2021

Exploring the Relationship Between Matriculation Model and Time to Enrollment in Engineering Graduation Major

Abstract

The Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) is used to explore when engineering students matriculate into the engineering majors from which they will graduate and expands the literature by evaluating the impacts of matriculation models. MIDFIELD records are used to determine each student's graduation major and the semester they first enrolled in that major. We additionally identify the matriculation model that each student matriculated under – a first-year engineering program or direct matriculation. Our results indicate that students who graduate from direct matriculation institutions enroll in their graduation majors 1.02 semesters after matriculation whereas students who graduate from institutions with first-year engineering programs have an average time to enrollment in graduation major of 2.34 semesters after matriculation. However, considering the time that students spend in first-year engineering programs, students at those institutions enroll in their graduation more quickly after their first opportunity than students at direct matriculation institutions.

Introduction

One of the most critical decisions first-year undergraduate students make is choosing their major. Many universities offer first-year engineering programs (FYEPs) that allow students to pre-select into engineering while delaying commitment to a specific engineering major until the conclusion of the first-year program. Even institutions that do not offer first-year programs often include a common first-year sequence that allows students to switch their engineering major without necessitating a delay to graduation.

Major selection has been studied at individual institutions [1], [2], and across multiple institutions [3], [4]. Some studies have focused on specific disciplines [5]–[7]. In this work, we focus on examining *when* students enroll in the major they will eventually graduate in and how it varies by matriculation model. The research questions this work will address are:

1. When do engineering students enroll in the major they are going to graduate in?
2. How does this vary by matriculation model?

Understanding when students enroll in their graduation majors can inform policies and program development as well as identify areas for improved "on-time" graduation rates.

Literature Review

Matriculation models vary across institutions. However, two matriculation models are more common – direct matriculation to engineering majors with common coursework required for all majors and first-year engineering programs where students are housed in a non-degree granting program before matriculating to their specific engineering major [8].

There are advantages to both models. A study by Orr *et al.* [9] found that 89% of students in FYEPs graduated in their first engineering major. The authors also found that students who matriculate directly to an engineering major also have a high graduation rate in that major at 78%. Direct matriculation models also help students avoid feeling disconnected from their future majors, which is sometimes problematic for FYEPs. However, students in FYEPs have slightly higher retention rates to the third semester compared to direct matriculation institutions [10].

A study by Brawner *et al.* [3] found that even though a matriculation model can have effects on students, few students were aware of the model used by institutions at the time of application. The same article also reported that students who enrolled in first-year engineering courses that included information about disciplines offered at their institutions were able to either confirm their discipline selection or use the information to make a discipline selection. A similar study also reported that required introduction to engineering courses could help students make discipline selection decisions as well as increase retention [11]. First-year engineering courses have also been described as having a "polarizing effect" on students' certainty in pursuing an engineering degree [12].

While first-year engineering courses have been found to have impacts on students, not all first-year engineering courses are the same, even among institutions with the same matriculation model. Reid and Reeping [13] developed a classification scheme to categorize the different types of first-year engineering courses based on course content. The scheme has eight unique categories for classification including Academic Advising, Math Skills, Design, and the Engineering Profession. It is more difficult to categorize courses over time because, as the authors note, these courses are often "designed by instructors to meet their preferred objectives" [13] which can lead to changes in course content over time. However, courses that focus on the Engineering Profession and Academic Advising are likely more beneficial to students deciding on or confirming their engineering major compared to courses that focus purely on the Math Skills and similar domains.

Theoretical Framework

This study is framed using Schneider's Attraction-Selection-Attrition Framework (ASA) [14]. This theory, from industrial & organizational psychology, uses its three namesake constructs to explain person-environment fit. As a result of the ASA cycle, organizations become homogenous and develop a culture, which is also influenced by the organizations' goals. Work by Godfrey [15], [16] on the cultures of the engineering disciplines shows there is evidence that these homogenized cultures already exist in the engineering majors.

ASA assumes that students are attracted to majors in which they are interested, and that the environment is a function of person and behavior. ASA will serve as the foundation of the framework for this study because of its assumptions that students who do not find fit in an environment are more likely to leave and those that do find fit are most likely to be retained. The outcome of these assumptions though is that majors are more likely to become more homogenous over time and develop a culture. Based on Godfrey's work, these cultures already exist in the engineering majors which speaks to the relevance of this framework.

ASA does not posit that individuals who do not find fit should leave an environment or an engineering major, only that individuals who do not find fit are most likely to leave. Therefore, students who are qualified and able to complete an engineering major may leave or be pushed out because of a lack of fit in the culture, which has been largely shaped by the White Male majority, when they could be successful in the major if they were retained.

Because the data used in this study are institutional records, conclusions about a student's fit in a major would be inappropriate. Therefore, the conclusions from this study will be limited to retention and persistence of the engineering majors.

Additionally, three common metaphors that have been used to describe persistence and attrition in engineering are the pipeline, pathway, and ecosystem [17]. Generally speaking, the pipeline metaphor is most restrictive because it assumes all students begin at the same point and are either retained to graduation or are lost along the way due to a "leak" in the pipe. While many students persist in one major from matriculation to graduation, it is not inclusive of students with major changes. While traditional, it has been argued that this metaphor has been favored because it has "worked for the dominant group" [18].

The second metaphor, an engineering pathway, allows for more options from enrollment to graduation including major changes and stop-outs. This metaphor is generally received more positively than pipelines because students play an active role in their degree path instead of being subjected to the system as in the pipeline metaphor [17].

The ecosystem metaphor, which is the third and final metaphor as well as the underlying metaphor for this work, takes the pathways metaphor multiple steps forward by looking at environments, such as departments, within the institution instead of viewing each student's pathway individually. Like the pathways metaphor, the ecosystem metaphor is also well accepted and has been the subject of at least one recent study [19]. This metaphor fits with the current study because we are interested in when students enroll in their graduation major. The ecosystem metaphor is most congruent because these questions are about a collect of students in an academic major and not individual students.

Data and Methodology

<u>Data Source</u>

This study utilized an existing national dataset, the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) [20]. The version of MIDFIELD used in this analysis was "fix9" of the database originally compiled on March 16, 2020.

This dataset provides longitudinal data for over 1.6 million students who began school during or after the Fall 1987 term; over 210,000 of whom declared an engineering major during their undergraduate careers [20]. The dataset is composed of data for all students who attended a collection of 17 schools, including primarily undergraduate institutions, historically Black universities, and R1 universities [21]. With this diversity of institution types, the MIDFIELD sample is generally representative of the United States engineering student population for racial and ethnic populations, but does overrepresent Black students and underrepresents Hispanic students [20], [22]. A description of the organizational structure of MIDFIELD is available [20].

Assigning Matriculation Models

In addition to the student data, MIDFIELD also includes policy summaries for each of the member institutions that describe admission requirements, matriculation practices, and degree progression [23]. These policy summaries combined with the Chen *et al.* taxonomy [8] informed the classification scheme used in this study.

The four different matriculation models used to describe the MIDFIELD institutions are:

1. FYE – First-Year Engineering Program; a formal program where all students take the same first-year classes with a formal designation as an FYEP student,
2. DtD – Direct to Department; students declare an engineering major when entering the university; some institutions still require common coursework,
3. Pre – Pre-engineering / pre-major; students are enrolled in pre-engineering or a major-specific pre-major; students must meet requirements to move to the degree-granting major, and
4. DtU – Direct to University; students do not have a major until certain requirements are met or a certain amount of time passes.

Due to a small number of students from a small number of institutions using the Pre and DtU matriculation models, students who matriculated under either of these matriculation models were excluded from analysis due to our inability to draw conclusions based on the sample available. The final sample includes students from 12 institutions; three institutions are classified as FYE and nine institutions are classified as DtD. All institutions maintained their matriculation model for the duration of the study period.

Inclusion Criteria

Because there are over 1.6 million student records in MIDFIELD from 17 institutions from students who ever attended those institutions since 1987, the sample of interest was identified from within the database. The identification and subsequent quantitative analysis were completed in the R programming language [24].

The final sample includes 48,664 students who:

- earned at least one degree in engineering,
- began school as a first-time-in-college student,
- matriculated into engineering,
- have six years of data available in MIDFIELD, and
- passed quality checks, as described below.

Quality checks were performed on the data to resolve any discrepancies across the MIDFIELD tables. Discrepancies were identified between the terms table and the student table. In discussions with the MIDFIELD Data Steward, who has expertise in research with institution records, the authors were advised to default to records in the terms table when resolving discrepancies between that table and the students table; we followed this advice. Additional discrepancies between the terms and degrees tables were also identified. The most frequent discrepancy was a mismatch between the last term recorded for a student in the terms table and the term the degree was awarded in the degree table. These students were retained because the exact term of graduation is not critical for this study. However, students whose degree was awarded in a different major than the major indicated in their graduation semester in the terms table were excluded. A total of 683 students were excluded for not passing this quality check.

Sample Demographics

The composition of the sample by race / ethnicity and sex is provided in Table 1. The median degree term for the sample is Spring 2002.

Table 1 – Sample by Race/Ethnicity and Sex as Reported in Institutional Data

	White	**Asian**	**Black**	**Inter-national**	**Hispanic / Latinx**	**Native American**	**Other / Unknown**
Male	63.3%	4.8%	3.3%	5.0%	2.0%	0.2%	1.5%
Female	14.4%	1.3%	2.1%	1.0%	0.6%	0.1%	0.4%

While most of the institutions included in this study use the DtD matriculation model, the distribution of students by matriculation model is closer to evenly split. This is because the three institutions using the FYE matriculation model are large, public institutions with well-established engineering programs, including their FYEPs.

The number of students by matriculation model and graduation major is shown in Table 2 for majors that graduate at least five percent of the sample population and are offered by at least one institution in each matriculation model. Engineering majors that graduate less than five percent of the sample or are only offered at institutions of one matriculation model are collected in the *otherEngr* designation. A designation of *nonEngr* is applied if a student is ever enrolled in a major outside of engineering.

Table 2 – Sample by Graduation Major

Grad Major	**Abbr.**	**DtD Institutions**	**FYE Institutions**	**TOTAL**
Mechanical	ME	7,004	4,402	11,406
Electrical	EE	4,116	3,416	7,532
Civil	CIV	3,672	3,694	7,366
Chemical	CHE	2,425	2,517	4,942
Industrial	IE	2,381	2,510	4,891
Aerospace	Aero	3,252	1,406	4,658
Computer	CPE	1,568	1,918	3,486
Other Engr	otherEngr	1,923	2,460	4,383
TOTAL		26,341	22,323	48,664

Enrollment in Graduation Major

The term of enrollment in graduation major was identified for each student by starting with their graduation term and working backward through time to check whether they were in their graduation major in each preceding term. This process identified the first term that the student enrolled in their graduation major and then did not leave the major until graduation. Working backward is important, so that students whose path is, for example, FYEP → Mechanical →

Civil → Mechanical → Graduation, are counted at the second instance of Mechanical because those students did not initially persist in the major. During this process, students' majors immediately before they enrolled in their graduation major (assuming the student has one), students' majors immediately after completing an FYEP (assuming the institution offered an FYEP) or otherwise leaving a general engineering designation at institutions without an FYEP, and the students' major during their third term (for general comparisons between FYE and DtD institutions) were all recorded.

The time difference between matriculation and enrollment in graduation major was calculated by counting the number of enrolled terms between matriculation term and term enrolled in graduation major, for each student. Results will be reported using the number of fall and spring (15-week) semesters with the following equivalencies:

- fall, winter, and spring (10-week) quarters are considered ⅔ of a semester,
- full summer (12-week) semesters are considered ⅘ of a semester, and
- partial summer (6-week) semesters are considered ⅖ of a semester.

Analysis

To answer the research questions, average times to enrollment in graduation major are compared across different groups using Welch's t-test. The results of the t-test allow for a determination of whether the two averages are statistically different or not. Additionally, the proportion of students enrolled in their graduation major by certain time points are also compared. Chi-Square Tests of Independence are used to determine whether the two proportions are statistically different or not.

In addition to determining the statistical significance of a t-test, Cohen's d can also be calculated as a measure of practical importance that is not influenced by sample size. Cohen's d has a minimum value of 0 meaning there is no practical difference but does not have a maximum value. However, there are generally accepted values for interpreting Cohen's d; values of 0.2 suggest a small effect, values of 0.5 suggest a medium effect, and values of 0.8 suggest a large effect [25]. With large samples, like those in this study, finding significant results using a Chi-Square Test of Independence is not uncommon [26]. Therefore, Cramer's V will be calculated to determine the effect size. Cramer's V can range from 0 to 1 meaning no association and perfect association, respectively. Between the extremes, values of 0.1 suggest a small effect, values of 0.3 suggest a medium effect, and values of 0.5 suggest a large effect [27].

Results and Discussion

Paths to Graduation Majors

Implicit in an investigation into the time it takes for engineering students to enroll in what will become their graduation majors comes an assumption that students do not always begin their undergraduate careers enrolled in that major. At DtD institutions, most students do matriculate to a degree-granting engineering major, though some choose a non-degree granting, undesignated, or undecided option. At FYE institutions, all students matriculate to an FYEP from which students then move to a degree-granting program. This requirement for students at FYE institutions essentially guarantees that the earliest a student at an FYE institution could be enrolled in their graduation major is one year after matriculation to the institution.

To confirm and visualize that not all students immediately matriculate to their graduation major, we created two Sankey diagrams, one for each type of institution – DtD in Figure 1 and FYE in Figure 2. In the left column of each diagram are students' first non-FYEP majors. For students at DtD institutions, this is normally the students' matriculation majors and at the FYE institutions, this is students' majors immediately after completing the required FYEP. The right column in each diagram is students' graduation majors. Engineering majors that enroll less than five percent of all students are collapsed into the *otherEngr* category. Students who matriculate to a non-engineering major after completing an FYEP are categorized as *nonEngr*. The width of the ribbon between each matriculation and graduation major indicates the relative number of students who follow that path.

At both types of institutions, most students never switch majors and graduate in their matriculation major or their first major after completing an FYEP. However, by visual comparison alone, there are more major changes at DtD institutions compared to FYE institutions. At DtD institutions, the most common changes are from matriculation in lower enrolled engineering majors in the *otherEngr* designation to graduation in Mechanical Engineering and Civil Engineering. The two most common changes at FYE institutions are from a first degree-granting major of Computer Engineering to graduation in Electrical Engineering and vice versa.

These visual differences between the institution types could partly be due to the fact that some major changes in the first year at FYE institutions are changes to intended engineering major (see [28]) that are not officially documented and therefore cannot be visualized in the Sankey diagram. Additionally, because engineering majors with lower enrollments were collapsed into the *otherEngr* designation, some students may switch between majors in this category, but these changes are not visualized on either Sankey diagram for simplicity and readability.

Given the potential time advantage students at DtD institutions have to enroll in their graduation majors at matriculation, but the increased frequency of students switching away from their matriculation majors at DtD institutions, the remainder of this paper will be an exploration of the time it takes students to enroll in their graduation majors at each institution type.

By Matriculation Model

Figure 3 shows the cumulative percentage of students enrolled in their graduation major by semester for both matriculation models. The figure shows that over 60% of students at DtD institutions enroll in their graduation major at matriculation. By nature of a required FYEP, no students at FYE institutions enroll in their graduation major at matriculation. However, there is a dramatic increase in the number of students enrolling in their graduation major after two semesters at FYE institutions, when most students become eligible to declare a degree-granting major.

By semester 4, over 90% of students in each matriculation model have enrolled in their graduation major and the cumulative percentage enrolled increases consistently toward 100% for both matriculation models. The average time that students at DtD institutions enroll in their graduation majors is 1.02 semesters after matriculation, indicated by the solid vertical line in

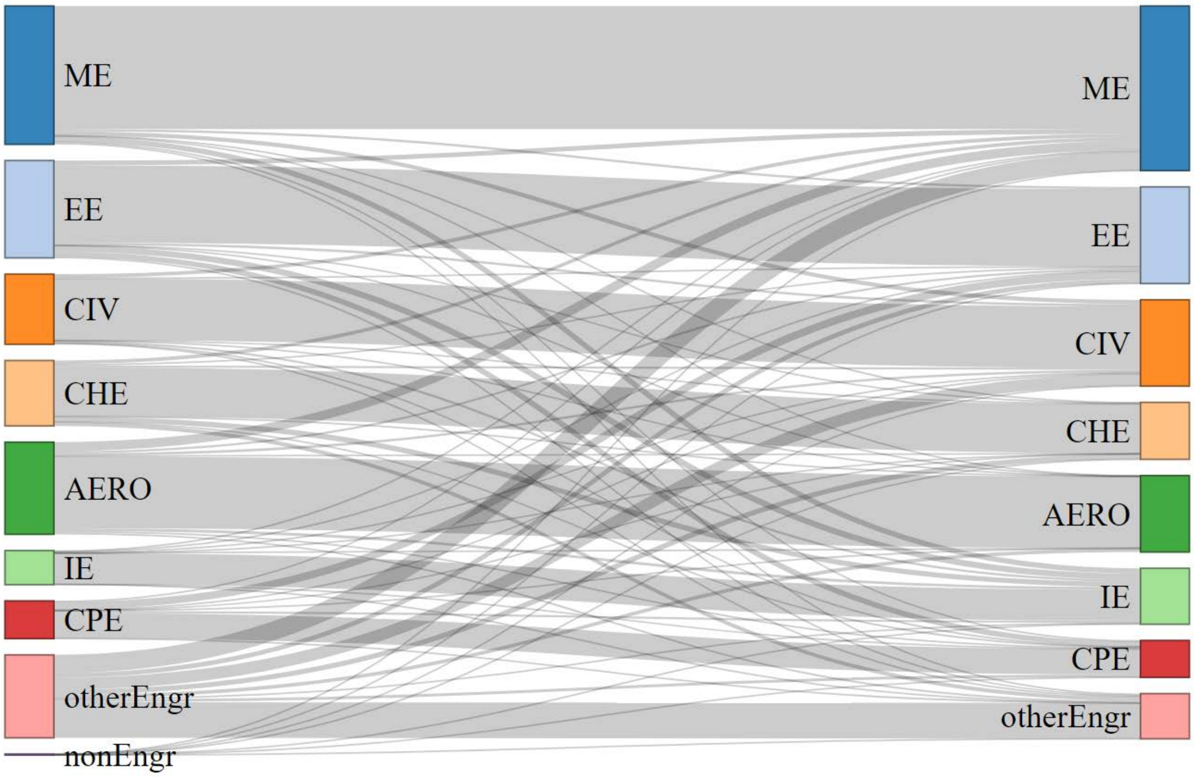

Figure 1 – Sankey Diagram for DtD Institutions

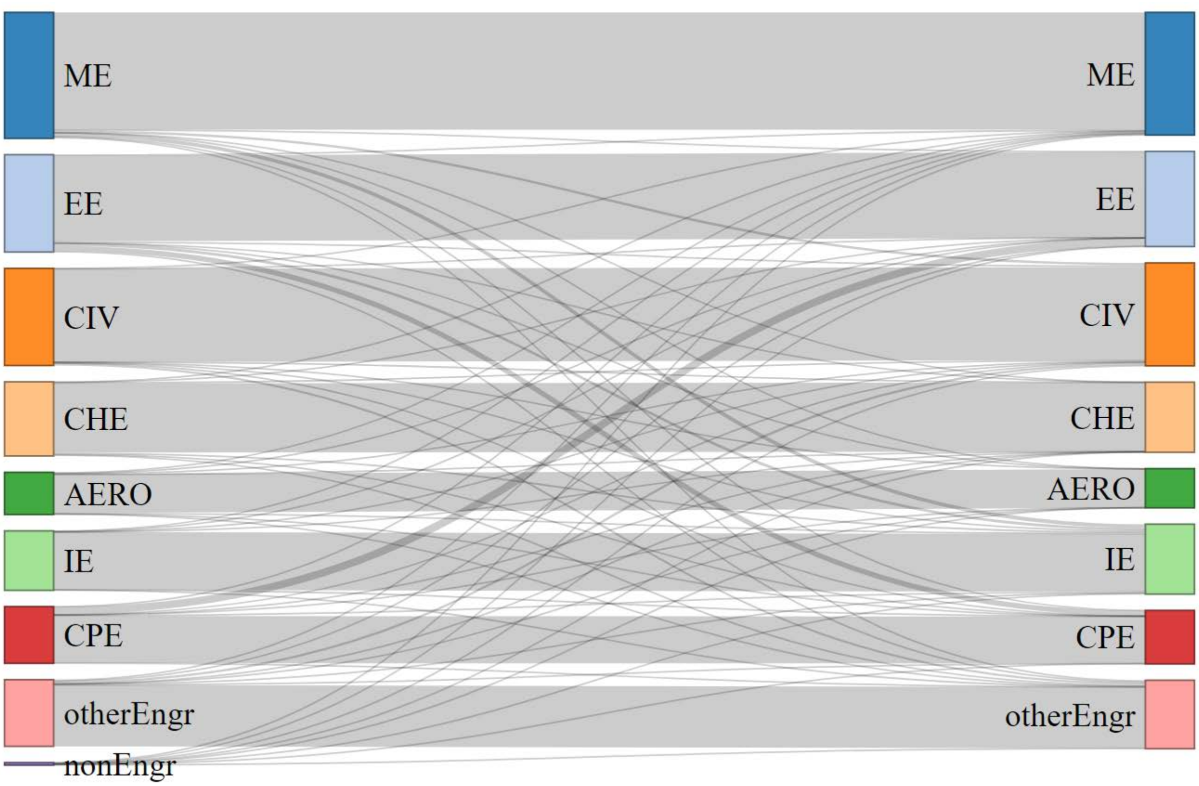

Figure 2 – Sankey Diagram for FYE Institutions

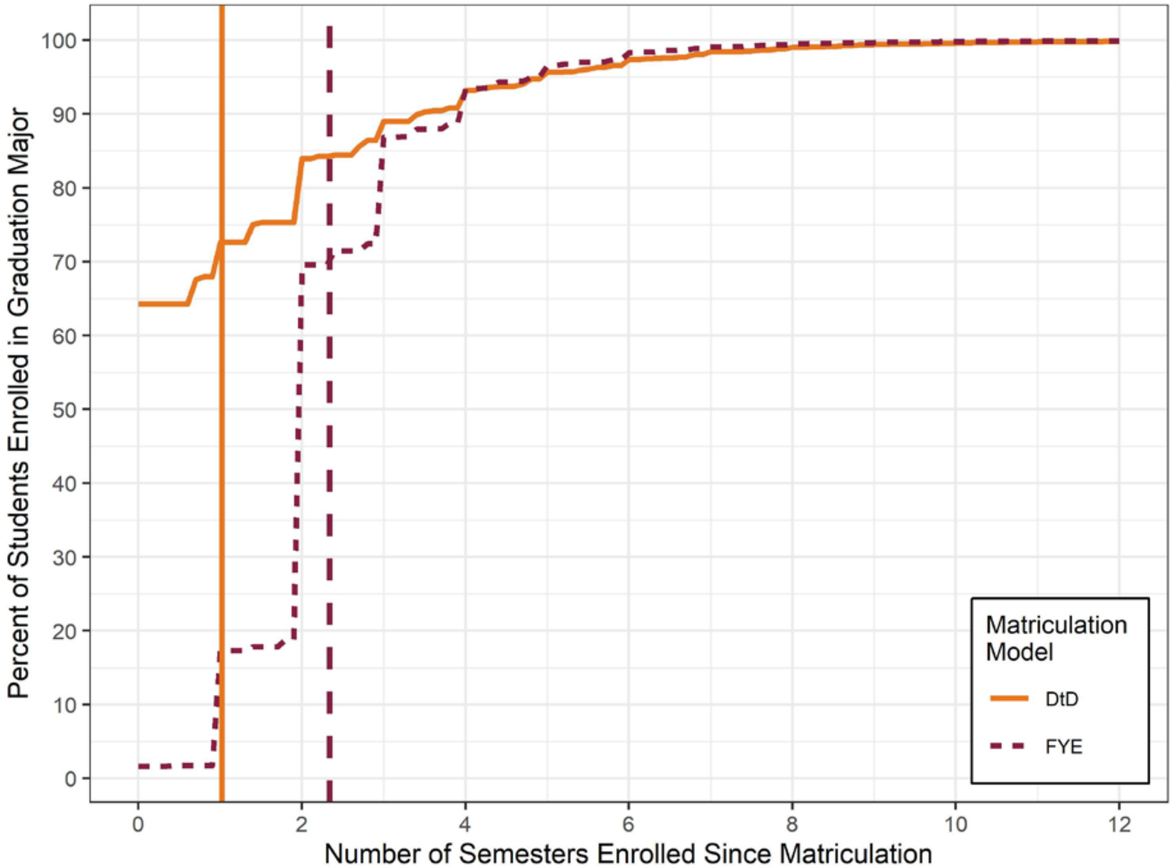

Figure 3 – Cumulative Percentage of Students Enrolled in Their Graduation Major by Matriculation Model (vertical lines indicate average time to enrollment for each matriculation model)

Figure 3; the median time to enrollment is 0 semesters. For students at FYE institutions, the average time to enrollment in graduation major is 2.34 semesters after matriculation, indicated by the dashed vertical line, and the median time to enrollment is 2 semesters.

Comparing these averages using Welch's t-test, the results are significantly different ($t = 92.02$, $df = 46745$, p-value ≈ 0) with an effect size, calculated using Cohen's d, of 0.825. Unsurprisingly, this result is both statistically different and meaningfully different given the structures of the two matriculation models. Students who are permitted to enroll in a degree-granting major at matriculation enroll in their graduation major sooner, on average, than students required to complete an FYEP.

While most students in each matriculation model enroll in their graduation major at their first opportunity, the difference of the averages of 1.32 semesters is less than the "on-time" difference of two semesters. One of the arguments in favor of a direct matriculation model is that it allows students to assimilate into their major and its culture more quickly than an FYEP allows [9]. The results presented here do not refute this suggestion but help contextualize this perceived advantage of the DtD matriculation model because students in the DtD model only enroll in their graduation major an average of 1.32 terms earlier than students who complete an FYEP, not two semesters (or one year) that might otherwise be expected.

Because the matriculation models are structurally different, in order to better compare the time it takes students to enroll in their graduation major after their first opportunity to do so, we determined the time that students at FYE institutions are enrolled in the required FYEP. After identifying the time a student was enrolled in the FYEP, that time was subtracted from the time to enrollment in graduation major since matriculation. Using this adjusted term of enrollment in graduation major, Welch's t-test was repeated. The average number of terms enrolled in an FYEP is 2.12 semesters and the median length of enrollment is 2 semesters.

While the average time to enrollment in graduation major of 2.34 terms after matriculation for students at FYE institutions, the average time to enrollment in graduation major is only 0.23 terms after completing the required FYEP. The median time to enrollment in graduation major after completing the required FYEP is 0 terms, which means that most students at FYE institutions enroll in their graduation major immediately after completing the FYEP. Comparing the averages of time to enrollment in graduation major after the first opportunity to do so using Welch's t-test, the results are significantly different ($t = -60.93$, $df = 38437$, p-value ≈ 0) with an effect size, calculated using Cohen's d, of 0.539.

This result indicates that students at FYE institutions enroll in their graduation major more quickly after their first opportunity (the completion of the FYEP) compared to when students at DtD institutions enroll in their graduation major after their first opportunity (matriculation to the institution). This result points to the idea that students use the first year to confirm whether or not to continue in engineering or a particular major [3], [12].

As a final comparison between matriculation models, we determined the number of students enrolled in their graduation major by their third term after matriculation. This determination provides an opportunity to compare the two models at the same time using a time when every "on-time" student has had the opportunity to enroll in a degree-granting major; additionally, because the median time of enrollment in an FYEP is 2 semesters at an FYE institutions, most students at FYE institutions have enrolled in a degree-granting major by semester 3. The number of students enrolled in their graduation major by their third semester since matriculation is shown in Table 3.

To determine if the percentage of students enrolled in their graduation major by the third semester for each of the matriculation models varied by matriculation model, we completed a Chi-Square Test of Independence. The test resulted in a significant difference ($\chi^2 = 1481$, $df = 1$, p-value ≈ 0), but this is possibly due to the large sample size. To accommodate for the large

Table 3 – Students Enrolled in Graduation Major by Semester 3 by Matriculation Model

	Total Number of Students	Enrolled in Graduation Major in Semester 3	
		Number of Students	Percentage of Students
DtD	26,341	22,327	84.8%
FYE	22,323	15,689	70.3%
All	48,664	38,016	78.1%

sample, we calculated Cramer's V which has a value of 0.175, which indicates a small effect in favor of the DtD matriculation model with respect to the proportion of students enrolled in their graduation major by term 3. This result helps qualify the previous findings that while students at FYE institutions matriculate to their graduation major very quickly after completing the FYEP, not all students have completed that requirement "on-time" by their third term.

Conclusions

It is not uncommon for engineering students to switch their engineering majors after matriculation to their institutions, as visualized in the Sankey diagrams in Figure 1 and Figure 2. Institutions where students matriculate directly to an engineering major see more major changes than institutions with an FYEP. However, many changes in *intended* engineering major are masked by the FYE designation.

On average, students who graduate from DtD institutions enroll in their graduation majors 1.02 semesters after matriculation, with a median time to enrollment of 0 semesters. And students who graduate from FYE institutions have an average time to enrollment in graduation major of 2.34 semesters after matriculation with a median time of enrollment of 2 semesters. However, when considering that students at FYE institutions spend an average of 2.12 semesters enrolled in the FYEP, students at FYE institutions enroll in their graduation more quickly after their first opportunity than students at DtD institutions. This result points to the idea that students use the first year to confirm whether or not to continue in engineering or a particular major. However, this finding is moderated by the fact that nearly 30% of FYE students are not enrolled in their graduation major after one year because they are either still enrolled in the FYEP or enrolled in a major other than their graduation major at the conclusion of the FYEP.

Future Work

The next steps in this work will be to investigate the time to graduation major by engineering major. Then, if warranted, a consideration by both students' graduation majors and matriculation model. Disaggregating by both factors will also allow us to determine how these two factors may be related to one another. Additional work will also include an investigation of the rates of persistence of these students in their first engineering majors and how rates of persistence vary by major and matriculation model. Visually, Figure 1 and Figure 2 provide evidence of different rates of persistence.

Limitations

Generalizability of these results are partially limited because the sample used in this study is more White than the current engineering population of the United States. While the institutions used in this study share common matriculation practices, all institutions of the same type are not necessarily identical to each other. For example, some institutions offer majors not available elsewhere and some may have enrollment criteria for specific engineering majors that exceed the requirements for engineering at large.

Acknowledgement

This material is based upon work supported by the National Science Foundation (NSF) under Grant No. 1545667. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

References

[1] A. Theiss, J. E. Robertson, R. L. Kajfez, K. M. Kecskemety, and K. L. Meyers, "Engineering Major Selection: An Examination of Initial Choice and Switching Throughout the First Year," in *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, 2016.

[2] J. L. Paulson, R. L. Kajfez, and K. M. Kecskemety, "Examining Engineering Students' Major Selection: Developing Baseline Quantitative Results to Investigate Major Selection and Change," in *Proceedings of the IEEE Frontiers in Education Conference*, 2016.

[3] C. E. Brawner, X. Chen, M. W. Ohland, and M. K. Orr, "The Effect of Matriculation Practices and First-Year Engineering Courses on Engineering Major Selection," in *Proceedings of the IEEE Frontiers in Education Conference*, 2013.

[4] G. Ricco, I. Ngambeki, R. A. Long, M. W. Ohland, and D. Evangelous, "Describing the Pathways of Students Continuing in and Leaving Engineering," in *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, 2010.

[5] K. M. Kecskemety and R. L. Kajfez, "Aeronautical and Astronautical Engineering and Mechanical Engineering Major Movement to Graduation," in *AIAA Aerospace Sciences Meeting*, 2018.

[6] M. Pilotte, M. W. Ohland, S. M. Lord, R. A. Layton, and M. K. Orr, "Student Demographics, Pathways, and Outcomes in Industrial Engineering," *Int. J. Eng. Educ.*, vol. 33, no. 2, pp. 506–518, 2017.

[7] K. Tanner, R. L. Kajfez, and K. M. Kecskemety, "Chemical Engineering Major Selection Throughout the First Year: A Mixed-Methods Approach," in *ASEE Annual Conference & Exposition*, 2018.

[8] X. Chen, C. E. Brawner, M. W. Ohland, and M. K. Orr, "A Taxonomy of Engineering Matriculation Practices," in *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, 2013.

[9] M. K. Orr, C. E. Brawner, S. M. Lord, M. W. Ohland, R. A. Layton, and R. A. Long, "Engineering Matriculation Paths: Outcomes of Direct Matriculation, First-Year Engineering, and Post-General Education Models," in *Proceedings of the IEEE Frontiers in Education Conference*, 2012.

[10] C. E. Brawner, M. M. Camacho, R. A. Long, S. M. Lord, M. W. Ohland, and M. H. Wasburn, "Work in Progress - The Effect of Engineering Matriculation Status on Major Selection," in *Proceedings of the Frontiers in Education Conference*, 2009.

[11] M. K. Orr, C. E. Brawner, M. W. Ohland, and R. A. Layton, "The Effect of Required Introduction to Engineering Courses on Retention and Major Selection," in *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, 2013.

[12] K. L. Meyers, G. W. Bucks, K. Harper, and V. E. Goodrich, "Multi-Institutional Evaluation of Engineering Discipline Selection," in *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, 2015.

[13] K. Reid and D. Reeping, “A Classification Scheme for ‘Introduction to Engineering’ Courses: Defining First-Year Courses Based on Descriptions, Outcomes and Assessment,” in *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, 2014.

[14] B. Schneider, “The People Make the Place,” *Pers. Psychol.*, vol. 40, no. 3, pp. 437–453, 1987.

[15] E. Godfrey, “Cultures within Cultures: Welcoming or Unwelcoming for Women?,” in *Proceedings of the American Society for Engineering Education Annual Conference*, 2007.

[16] E. Godfrey, “Understanding Disciplinary Cultures: The First Step to Cultural Change,” in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds. New York, NY: Cambridge University Press, 2014, pp. 437–456.

[17] W. C. Lee, “Pipelines, Pathways, and Ecosystems: An Argument for Participation Paradigms,” *J. Eng. Educ.*, vol. 0, no. October 2018, pp. 1–5, 2019.

[18] K. H. Fealing, Y. Lai, and J. Myers, Samuel L., “Pathways vs. Pipelines to Broading Participation in the STEM Workforce,” *J. Women Minor. Sci. Eng.*, vol. 21, no. 4, pp. 271–293, 2015.

[19] S. M. Lord, M. W. Ohland, R. A. Layton, and M. M. Camacho, “Beyond Pipeline and Pathways: Ecosystem Metrics,” *J. Eng. Educ.*, vol. 108, no. 1, pp. 32–56, 2019.

[20] M. W. Ohland and R. A. Long, “The Multiple-Institution Database for Investigating Engineering Longitudinal Development: An Experiential Case Study of Data Sharing and Reuse,” *Advances Eng. Educ.*, vol. 5, no. 2, 2016.

[21] “Multiple-Institution Database for Investigating Engineering Longitudinal Development.” [Online]. Available: https://engineering.purdue.edu/MIDFIELD/index.html. [Accessed: 31-Jul-2020].

[22] M. K. Orr, M. W. Ohland, S. M. Lord, and R. A. Layton, “Comparing the Multiple-Institution Database for Investigating Engineering Longitudinal Development with a National Dataset from the United States,” *Int. J. Eng. Educ.*, vol. 36, no. 4, pp. 1321–1332, 2020.

[23] C. E. Brawner, “MIDFIELD Institutional Policy Summaries.”

[24] R Core Team, “R: A Language and Environment for Statistical Computing.” R Foundation for Statistical Computing, Vienna, Austria, 2020.

[25] J. Cohen, “The t Test for Means,” in *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed., Hillsdale, NJ: Lawrence Erlbaum Associates, 1988, pp. 19–74.

[26] S. Bialosiewicz, K. Murphy, and T. Berry, “An Introduction to Measurement Invariance Testing: Resource Packet for Participants,” in *American Evaluation Association*, 2013.

[27] J. Cohen, “Chi-Square Tests for Goodness of Fit and Contingency Tables,” in *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed., Hillsdale, NJ: Lawrence Erlbaum Associates, 1988, pp. 215–272.

[28] K. M. Ehlert, M. L. Rucks, B. A. Martin, and M. K. Orr, “Predictors of Matriculation in Intended Major in a First-Year Engineering Program,” in *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, 2019.