2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #53616

Investigating the Relationship Between Curricular Complexity and Ecosystem Metrics

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Abstract

This paper concerns exploring the relationship between measures of curriculum complexity and "ecosystem metrics" that expand on the concepts of retention and graduation rates. Although prior research in engineering education has explored retention and course progression, fewer studies have addressed how the curriculum design itself influences the broader flow of students across disciplines. An emerging approach to quantifying curricular complexity, called Curricular Analytics, offers a new lens to address this research gap. This approach treats the prerequisite and corequisite relationships in a curriculum as a network to calculate a total measure that can be used to compare programs and correlate with student outcomes of interest. Previous work has established that the total measure, called structural complexity, is negatively correlated with completion rates. However, correlations with broader metrics used in the literature, called ecosystem metrics, have not been explored. Unlike completion rates, ecosystem metrics seek to capture more nuanced ways in which students engage with the curriculum, such as major switching. Accordingly, we pose the following research question: *"How do the measures of curricular complexity within Curricular Analytics relate to ecosystem metrics?"*

We explore two measures of curricular complexity: structural complexity and curricular rigidity. Structural complexity is the sum of the blocking and delay factors of all courses within a curriculum. The blocking factor for a course is the number of courses a student cannot take if they fail it; the delay factor for a course is the longest prerequisite chain to which it belongs. We also use a simpler form of structural complexity as a comparison metric, called curriculum rigidity. Curriculum rigidity is the density of prerequisite relationships, the total number of prerequisites and corequisites divided by the number of courses. We used two student outcome measures: stickiness, defined as the percentage of students who ever declare a discipline and ultimately graduate in that same field, and migration yield, the percentage of students who transfer into and successfully graduate from a new discipline.

We used program plans of study ($n = 48$) collected from 13 institutions across five engineering disciplines in the Multiple-Institution Database for Investigating Longitudinal Development (MIDFIELD), including student records (i.e., major and graduation indicators). Complexity measures were calculated for a specific cohort year. We approached the data using a correlational design.

Our results showed that more structurally complex curricula tend to weakly correspond with lower stickiness ($r(46) = -0.07$) and migration yield ($r(46) = -0.05$), and the curriculum rigidity negatively and weakly correlate with stickiness ($r(46) = -0.10$) and migration yield ($r(46) = -0.06$), suggesting that curricular design can constrain in small ways, but not fully determine or explain student persistence and mobility.

Introduction

Student persistence in higher education - and in engineering in particular - has long been a central concern for researchers and educators, as it reflects both individual student success and the effectiveness of educational systems. Prior analyses using large institutional datasets, such as the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD), have revealed substantial gender and racial disparities in persistence and migration patterns among engineering students [1]. While these studies provide valuable insight into how students move through engineering programs, they have largely remained descriptive - documenting outcomes without accounting for how the structure of the curriculum itself may shape those trajectories. As a result, the role of curricular design in producing or reinforcing these patterns remains underexplored. To address this gap, the current study integrates curricular data with metrics describing the broader curricular ecosystem, offering a structural perspective on how the architecture of engineering programs may facilitate or hinder diverse pathways through engineering.

Accordingly, this study sought to establish preliminary empirical evidence linking curricular complexity metrics with so-called ecosystem-level metrics, such as stickiness and migration yield, that quantitatively characterize pathways into and through different programs. Stickiness refers to the proportion of students who declare a discipline and ultimately graduate in that same discipline, while migration yield captures the proportion of students who enter a discipline from another major and successfully graduate in it. Specifically, we examine how two measures derived from Curricular Analytics that measure how complex a program actually is, *structural complexity* and *curriculum rigidity*, relate to these ecosystem outcomes across five engineering disciplines and 13 U.S. institutions represented in the MIDFIELD database.

This work applies the concept of analyzing engineering programs' ecosystems, as proposed by Lord et al. [2], which conceptualizes engineering programs as interdependent systems in which multiple interacting forces, including curricular structures, shape student movement. By embedding quantifiable features of curricular design into this framework, this analysis tests whether more structurally complex or rigid curricula correspond with lower student persistence and reduced migration success.

Research Aim

This study aims to illuminate how curriculum design can both constrain and enable flexible, inclusive educational ecosystems that support diverse student success in engineering.
Accordingly, we pose the following research question: *"How do the measures of curricular complexity within Curricular Analytics relate to ecosystem metrics?*

Literature Review

Engineering education researchers increasingly draw on ecological frameworks to understand how students persist, migrate between majors, and experience engineering programs. Lord et al.'s [2] ecosystem approach reframes engineering education not as a linear pipeline, but as an interconnected system in which students, curricula, faculty culture, and institutional policies interact dynamically. From this perspective, engineering pathways are inherently nonlinear and multi-directional: students may switch majors, stop out, or return through alternative routes.

Within this broader ecosystem, the curriculum serves as a central structural subsystem that both organizes and constrains student movement. Cultural research in engineering education [3–6] further demonstrates that these structural elements are not neutral; they interact with disciplinary norms and identity processes, reinforcing tacit hierarchies that shape students' sense of belonging and their ability to navigate rigorous course sequences. Complementing this work, research on ecological belonging interventions shows that even small changes to classroom microenvironments can improve retention among women, Black, Latino/a/x, and Indigenous students, underscoring how local contexts operate within – and can reshape – larger institutional ecosystems.

To quantify patterns within these ecosystems, Ohland et al. [7] and Lord et al. [2, 8] introduced ecosystem metrics, such as stickiness and migration yield. Stickiness captures the proportion of students who ever declare a major and ultimately graduate in it, while migration yield reflects the proportion of students who enter a major from another discipline and graduate from it. Together, these measures reveal dynamics that traditional retention statistics often obscure—for instance, that students who migrate into a major frequently graduate at higher rates than those who begin there, and that disciplinary and demographic disparities persist even when overall retention appears stable [2].

Explaining variation in these patterns requires attention to the structural features of academic programs, particularly curricular complexity. Heileman et al. [9] developed graph-theoretic measures – including blocking factor, delay factor, cruciality, and structural complexity – to characterize the organization of curricula. Programs with higher complexity tend to have long prerequisite chains, tightly coupled course sequences, and limited scheduling flexibility. Subsequent research [10, 11] shows that such features can create bottlenecks that slow student progression and disproportionately disadvantage those who enter a major later or transfer from another institution.

Despite these advances, the relationship between curricular complexity and ecosystem-level outcomes remains underexplored. While prior work has linked complexity to outcomes such as time-to-degree and course bottlenecks [12, 13], few studies have examined how it relates to ecosystem metrics, such as stickiness and migration yield. Likewise, ecological models of student migration have rarely incorporated formal measures of curriculum structure. This disconnect represents a critical gap in understanding how structural and behavioral dimensions of engineering education intersect.

The Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) provides a powerful platform to address this gap. MIDFIELD-based studies have documented national patterns in persistence, migration, and inequities across gender and race [14]. However, because MIDFIELD does not inherently include curricular network data, these analyses have been limited in their ability to assess how program structure contributes to observed disparities. Emerging work that integrates MIDFIELD with Curricular Analytics [15, 16] begins to bridge this divide, enabling researchers to examine how program architecture interacts with ecosystem-level student movement.

Taken together, these strands of literature suggest a compelling opportunity for integration. Ecosystem metrics offer powerful tools for capturing program-level patterns of persistence and migration beyond traditional measures [2, 7], while curricular complexity provides a structural lens for understanding variation in student mobility [9-11]. Yet, few multi-institutional studies have brought these perspectives together to examine how curricular design relates to ecosystem behaviors across diverse student populations. As a result, it remains unclear whether and in what ways curricular structural features are associated with observed differences in stickiness and migration yield across demographic groups.

Research Design

This study employed a correlational research design to examine associations between curricular complexity metrics and ecosystem-level outcomes. Because the primary analyses focus on relationships between program-level variables, an a priori power analysis was conducted to determine the minimum sample size required to detect a meaningful effect. Based on prior work suggesting large correlations between complexity and graduation rates [9, 11], we assume a large effect size ($r = 0.50$), a negative directional relationship (one-tailed test), a conventional significance level ($\alpha = 0.05$), and desired statistical power ($1 - \beta = 0.80$). Our power analysis indicated a minimum required sample size of 21 plans of study. This power analysis was conducted using G*Power [17]. The final analytic sample included 48 discipline–institution programs, exceeding the minimum requirement and providing adequate power to detect the expected effects.

Data Sources

This study integrates two complementary datasets: (1) program plans of study collected from 13 institutions, and (2) student-level enrollment and graduation data from the MIDFIELD database.

Curricular data were compiled from 13 institutions (University of Oklahoma, University of Colorado, Utah State University, Colorado State University, University of North Carolina Charlotte, Embry–Riddle Aeronautical University - Daytona Beach, South Dakota School of Mines and Technology, Embry–Riddle Aeronautical University – Prescott, Purdue University, Clemson University, Florida A&M University, University of Florida) in MIDFIELD across five engineering disciplines: mechanical, electrical, civil, chemical, and industrial engineering ($n = 48$). For each institution, we retrieved official program catalogs and degree requirements documents from institutional archives. We then extracted information for each course in the program of study, including the course title, course number, credit hours, recommended term, and prerequisites and corequisites.

To convert the curricula into directed graphs used for complexity calculations, prerequisite and corequisite relationships were mapped as directed edges. When catalogs listed complex prerequisite logic (e.g., “CHEM 1040 and MATH 1910, or CHEM 1070”), these conditions were systematically resolved by applying a consistent coding protocol developed within the research team. Full details of the data collection process can be found in [15] and [18].

For student-level enrollment and graduation data from the MIDFIELD database, all data were extracted from three core tables: the student table, term table, and degree table, which together provided information on students’ enrollment histories, term-by-term major declarations, degree outcomes, and curricular structure. To identify engineering majors, we relied on CIP codes, a six-digit taxonomy used to categorize educational programs. Specifically, Mechanical

Engineering programs were identified using CIP codes beginning with 1419; Electrical Engineering, 1410; Civil Engineering, 1408; Chemical Engineering, 1407; and Industrial Engineering, 1435. These CIP codes were used to extract the target engineering majors from the MIDFIELD dataset. A six-year graduation window was applied for both measures.

For the stickiness calculation, we identified students who entered a specific major at any point and graduated in the same major within six years. For example, in Mechanical Engineering, we selected students who entered the program in 2012 and graduated between 2012 and 2018, provided that their degree was awarded in Mechanical Engineering. Applying this procedure across 13 institutions and five engineering disciplines, the resulting sample included 5951 students used to compute stickiness.

For the migration measure, we focused on students who transitioned into a given major after their first year and subsequently graduated in that major. Using the same CIP codes, majors were identified consistently across institutions. For example, when calculating migration into Electrical Engineering at a given institution, we identified students who entered the university in 2012 but were not declared as Electrical Engineering majors in their first year. Students who later declared Electrical Engineering in any term between their second and sixth year were classified as migrants, provided that they ultimately graduated in Electrical Engineering. Using this definition, the total sample size for migration across the same institutions and disciplines was approximately 2413 students.

Correspondingly, curriculum complexity metrics, including structural complexity and curriculum rigidity, were computed using the plans of study associated with the same entering cohort. This temporal alignment ensures conceptual consistency between the curriculum's structural characteristics and the ecosystem-level outcomes observed for the same group of students. As a result, the final dataset integrates ecosystem and curriculum complexity metrics for 13 institutions and 48 programs of study, enabling direct cross-program and cross-institutional comparisons.

Analysis

Two measures of curricular complexity from the Curricular Analytics framework were used in this study: *structural complexity* and *curriculum rigidity*. Both metrics quantify how prerequisite and corequisite relationships shape the architecture of an academic program, offering a structural perspective on how curricula may constrain or enable student movement [9-11].

Structural complexity [9] is the total interconnectedness of a curriculum, calculated by summing the blocking and delay factors for each course. For a given course v_i, the blocking factor $b_c(v_i)$ is defined as the number of downstream courses that a student cannot take if they fail or delay the course. The delay factor $d_c(v_i)$ captures the length of the longest prerequisite chain in which the course participates, representing how deeply the course is embedded within the curriculum. The structural contribution of each course is therefore:

$$c(v_i) = b_c(v_i) + d_c(v_i) \qquad (1)$$

The overall structural complexity for a curriculum with n courses, denoted by α_c, is:

$$\alpha_c = \sum_{i=1}^{n} c(v_i) \tag{2}$$

Higher values of α_c indicate curricula with long prerequisite chains and large sets of courses dependent on early foundational subjects. These features may increase the likelihood of bottlenecks, scheduling conflicts, or delayed progression.

Curriculum rigidity provides a more straightforward comparison metric that captures how densely connected a curriculum is [19, 20]. The goal of curriculum rigidity is to measure the overall complexity of the curriculum, just as with structural complexity, but the operationalization is much simpler. Rigidity is computed as the ratio of the total number of prerequisite and corequisite edges (E) to the number of courses (V) in the curriculum:

$$\alpha_c = \sum_{i=1}^{n} c(v_i) \tag{3}$$

Programs with high rigidity (i.e., $c_r > 1$) have limited flexibility in course sequencing because prerequisite relationships structurally constrain a larger proportion of courses. In contrast, lower rigidity (i.e., $c_r < 1$) indicates greater potential for alternative course-taking pathways, schedule adaptability, and entry points for students who migrate into a major.

Ecosystem Metrics

Following Lord et al. [2], two ecosystem metrics were computed: stickiness, defined as the number of students who graduated in a specific discipline divided by the number of students who ever declared that discipline as a major.

$$\text{Stickiness} = \frac{\text{number of students who graduated in discipline X}}{\text{number of students who ever declared discipline X}} \tag{4}$$

This metric reflects a program's internal cohesion. For example, if 100 students declare mechanical engineering and 60 graduate in mechanical engineering, then the stickiness for mechanical engineering is 0.60. Second, we calculated migration yield, which can be thought of as a more restrictive version of stickiness. Instead of counting everyone who ever declared a particular major, migration yield restricts the count to only those who transitioned to that major from another, i.e., students who "migrated" into that discipline. The numerator is similar to stickiness, counting the number of migrating students who graduated in that discipline. This captures how well programs integrate students entering from other majors:

$$\text{Migration Yield} = \frac{\text{number of students who graduated in discipline X}}{\text{number of students who migrated into discipline X}} \tag{5}$$

All analyses were conducted in R using the CurricularComplexity package [21]. Each metric was computed at the discipline × institution level. To characterize variation across programs, descriptive statistics were calculated for structural complexity, curriculum rigidity, stickiness, and migration yield. Pairwise correlations using Pearson's *r* were then calculated between each curricular complexity metric (structural complexity and curriculum rigidity) and each ecosystem metric (stickiness and migration yield).

Results

Descriptive Patterns Across Programs

Descriptive statistics for the four focal variables, stickiness, migration yield, structural complexity, and curriculum rigidity, are reported in Table 1. Stickiness ranged from 0.19 to 0.92 (M = 0.52, SD = 0.21), indicating substantial variation across engineering programs in the extent to which students who declare a major ultimately graduate in that same discipline. The distribution of stickiness exhibited positive skew (skewness = 0.53) and was leptokurtic (excess kurtosis = 2.18), suggesting a slight concentration of programs with relatively higher persistence outcomes.

Migration yield ranged from 0.21 to 1.00 (M = 0.61, SD = 0.19), reflecting meaningful differences in how effectively programs integrate and graduate students who migrate into a discipline from another major. Unlike stickiness, migration yield exhibited near-symmetry (skewness = –0.04) with higher kurtosis (2.24), indicating a more balanced distribution across programs.

Structural complexity varied widely across the sample, ranging from 116 to 520 (M = 291.85, SD = 97.22), highlighting substantial differences in curriculum architecture across institutions and engineering disciplines. Its distribution showed moderate positive skew (0.41) and high kurtosis (2.57), suggesting a small number of highly complex curricula relative to the overall sample. Curriculum rigidity also demonstrated notable variation (M = 0.92, SD = 0.28; range = 0.45–1.51), with relatively symmetric distributional properties (skewness = 0.29; kurtosis = 2.39).

Taken together, these descriptive patterns reveal considerable diversity in both ecosystem outcomes and curricular structures across engineering programs. While stickiness and migration yield varied across a moderate range, structural complexity and curriculum rigidity exhibited substantial dispersion, underscoring the importance of examining both central tendencies and distributional characteristics when assessing program-level ecosystem behavior.

Table 1. Descriptive statistics for stickiness, migration yield, structural complexity, and curriculum rigidity across engineering programs (N = 48 discipline–institution programs).

Variable	Mean	SD	Min	Max	Skewness	Kurtosis
Stickiness	0.52	0.21	0.19	0.92	0.53	2.18
Migration yield	0.61	0.19	0.21	1.00	-0.04	2.24
Structural complexity	291.85	97.22	116	520	0.41	2.57
Curriculum rigidity	0.92	0.28	0.45	1.51	0.29	2.39

Relationships Between Curricular Complexity and Ecosystem Metrics

Pearson correlation coefficients among stickiness, migration yield, structural complexity, and curriculum rigidity are summarized in Table 2.

Table 2. Pearson correlation matrix among stickiness, migration yield, structural complexity, and curriculum rigidity for 48 discipline–institution engineering programs

	Stickiness	Migration Yield	Structural Complexity
Migration yield	0.74		
Structural complexity	-0.07	-0.05	
Curriculum rigidity	-0.10	-0.06	0.75

Stickiness and migration yield were strongly and positively correlated ($r(46) = 0.74$, $p < .001$), indicating that programs with higher internal retention also tend to graduate a larger proportion of students who migrate into the major. Structural complexity and curriculum rigidity were also strongly and positively correlated, $r(46) = 0.75$, $p < .001$ (Table 2). Programs with higher structural complexity generally correspond to higher curriculum rigidity values.

In contrast, relationships between curricular complexity metrics and ecosystem outcomes were weak in magnitude and not statistically significant. The relationship between structural complexity and stickiness was negative and small ($r(46) = –0.07$, $p = .620$), as shown in Figure 1 (left), which depicts a shallow downward trend with substantial dispersion across programs. A similarly weak negative association was observed between structural complexity and migration yield ($r(46) = –0.05$, $p = .723$), illustrated in Figure 1 (right).

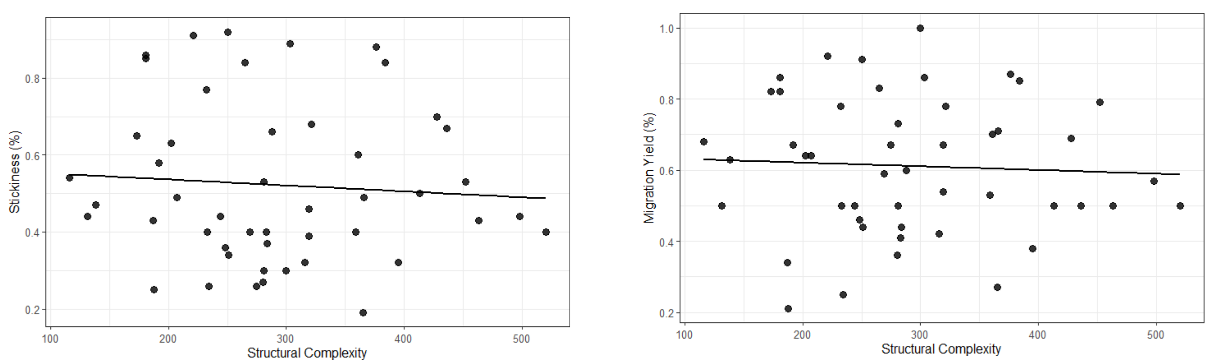

Figure 1. Structural Complexity and Stickiness Across Engineering Programs (left), Structural Complexity and Migration Yield Across Engineering Programs (right)

Curriculum rigidity exhibited comparable patterns. As shown in Figure 2 (left), curriculum rigidity was weakly and negatively related to stickiness ($r(46) = –0.10$, $p = .517$), while Figure 2 (right) illustrates a similarly small negative relationship between curriculum rigidity and migration yield ($r(46) = –0.06$, $p = .684$). Although the direction of these relationships aligns with theoretical expectations that more constrained curricula may inhibit student persistence and migration, the scatter in the figures underscores that curricular structure alone explains little of the observed variation in ecosystem outcomes.

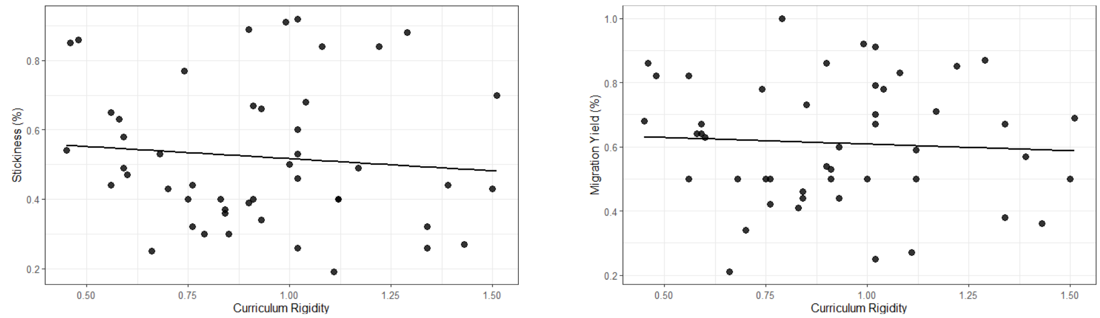

Figure 2. Curriculum Rigidity and Stickiness Across Engineering Programs (left), Curriculum Rigidity and Migration Yield Across Engineering Programs (right)

Discussion

This study sought to integrate two strands of engineering education research that are rarely examined together: curricular complexity metrics derived from Curricular Analytics and ecosystem metrics that characterize student persistence and migration. Consistent with prior work on ecosystem thinking [2], the results demonstrate that stickiness and migration yield are strongly related, suggesting that programs that retain students internally also tend to integrate and graduate students who migrate into the major. This finding reinforces the conceptualization of engineering programs as dynamic systems in which internal cohesion and openness to new entrants are mutually reinforcing rather than competing outcomes.

At the same time, the relationships between curricular complexity metrics and ecosystem outcomes were weak in magnitude. Although both structural complexity and curriculum rigidity exhibited negative associations with stickiness and migration yield, these relationships were small and not statistically significant. This pattern contrasts with prior studies that found stronger negative relationships between curricular complexity and completion-related outcomes [9, 11]. One explanation for this difference is that ecosystem metrics capture broader, more flexible measures of student movement than completion rates alone. Whereas completion metrics are sensitive to bottlenecks and delays embedded in prerequisite structures, ecosystem outcomes may also reflect institutional supports, advising practices, departmental cultures, and students' strategic navigation of constraints. Curriculum design appears to function as one structural layer within a broader educational ecosystem, interacting with social, institutional, and cultural factors that shape student persistence and migration [22].

Importantly, the weak relationships observed here should not be interpreted as evidence that curriculum structure is unimportant. Rather, they suggest that the influence of curricular complexity may be indirect or contingent, operating through mechanisms such as advising load, course availability, or students' prior preparation. From an ecosystem perspective, curricular complexity may shape the conditions under which students navigate programs, but institutional practices and student experiences mediate those conditions. This interpretation aligns with prior work demonstrating that curricular reform alone is insufficient to address inequities in engineering pathways without concurrent changes to climate, pedagogy, and support structures [4, 23].

Implications

The findings suggest that curricular structure represents one component of a broader educational ecosystem that shapes student persistence and migration, but that its influence is minor relative to the overall variability observed across programs. Programs with lower structural complexity and greater curricular flexibility tended to exhibit higher stickiness and migration yield, indicating that curriculum architecture can support healthier student movement through engineering pathways. However, substantial variation even among programs with comparable levels of complexity underscores that curriculum design alone is insufficient to explain ecosystem outcomes.

From an analytical perspective, the findings also highlight the value of pairing curricular analytics with ecosystem metrics. While curricular complexity metrics capture structural constraints, ecosystem metrics reveal how students collectively respond to those constraints, offering complementary lenses for understanding program-level behavior.

Limitations

Several limitations should be considered when interpreting these findings. First, this study relies on program-level aggregated data, which limits the ability to examine individual student experiences, course-taking pathways, or within-program variation. As a result, the analyses cannot capture heterogeneity in how students navigate curricular structures or how specific subgroups experience constraints differently.

Second, all analyses are correlational, and causal inferences cannot be drawn from the observed relationships. Although curricular complexity metrics are theoretically linked to persistence and migration, the direction and mechanisms of influence cannot be established using the present design.

Third, the sample is limited to 48 programs (primarily at large R1 institutions), thereby limiting statistical power to detect weaker relationships. Including a larger number of institutions and programs could increase power and enable more precise estimation of smaller effects, particularly for subgroup analyses.

Finally, the curricular complexity metrics employed here focus on structural properties of prerequisite networks and curricular organization. They do not account for instructional practices, advising quality, departmental climate, or other contextual features that may substantially influence student persistence and migration. These omitted factors likely contribute to the modest cross-domain relationships observed between curricular structure and ecosystem outcomes.

Future Work

Future research should build on these findings by incorporating student-level pathway data to examine how individuals navigate curricular structures over time. Multilevel modeling approaches that integrate student, curricular, and institutional factors may provide greater insight into how structural complexity interacts with advising practices, instructional experiences, and institutional context to shape persistence and migration.

Expanding the dataset to include additional institutions and engineering programs would increase statistical power and enable the detection of weaker relationships that may not be observable in smaller samples. Future studies could also explore longitudinal changes in ecosystem metrics following curricular redesign efforts to assess whether reductions in structural complexity translate into meaningful improvements in stickiness and migration yield.

Finally, research that centers on the experiences of marginalized student groups is needed to better understand the sources of persistent demographic disparities in ecosystem outcomes. Integrating curricular analytics with qualitative and mixed-methods approaches may help identify mechanisms through which curricular structures, institutional practices, and student identities jointly shape engineering pathways.

Conclusion

This study examined how program-level curricular complexity metrics relate to ecosystem-level outcomes of student persistence and migration across engineering programs. By integrating structural complexity and curriculum rigidity with ecosystem metrics such as stickiness and migration yield, the analysis provides a multilevel view of how curricular design and student movement interact within engineering education systems.

The findings indicate that ecosystem metrics are strongly related to one another, as are curricular complexity metrics, while the relationships between curricular structure and ecosystem outcomes are present but modest at best. This pattern suggests that curricular architecture alone does not determine student persistence or migration but instead functions as one structural component within a broader educational ecosystem. Consistent with ecosystem-oriented frameworks, student movement through engineering programs appears to be shaped by an interplay of curricular constraints, institutional practices, advising structures, and student experiences.

Importantly, demographic disparities in ecosystem outcomes persisted across levels of curricular complexity and rigidity. Underscoring that curricular redesign by itself is unlikely to resolve long-standing inequities in engineering pathways. These results highlight the need for integrated approaches that pair curriculum reform with institutional and cultural interventions to support diverse student populations.

Taken together, this work contributes to engineering education research by demonstrating the value of combining curricular analytics with ecosystem metrics to better understand program-level behavior. Rather than treating curricular complexity as a singular explanatory factor, the study advances an ecosystem perspective that recognizes curriculum as one of several interacting structures shaping student trajectories. This framing provides a foundation for future research and institutional decision-making focused on creating more navigable, equitable, and resilient engineering education ecosystems.

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