

Effects of Large-Scale Programmatic Change on Electrical and Computer Engineering Transfer Student Pathways

David Reeping¹, Member, IEEE, Dustin M. Grote, and David B. Knight

Abstract—Contribution: This article details the potential impacts of a curricular revision at a four-year institution on electrical and computer engineering (ECE) vertical transfer students using Heileman *et al.*'s curricular complexity framework.

Background: The curriculum refresh was prompted by a National Science Foundation funded program called “Revolutionizing Engineering Departments”—encouraging departments to radically shift their curricula and cultures such that it is not possible to complete a one-to-one mapping between the former curriculum and new curriculum. The purpose of the study was to examine the extent to which transfer students could integrate into the new curriculum.

Research Questions: This article addresses the following research question, “how did the structural complexities of the transfer student pathways into the ECE degree programs change from their previous iterations?”

Methodology: Plans of the study were collected from 12 community colleges that had articulated pathways into ECE bachelor's degree programs ($n = 24$ plans of study) at a four-year institution and aligned those plans with the university pathways both before and after the radical curricular change. The complexities of transfer degree pathways of the old and new curriculum were compared using Heileman *et al.*'s structural complexity metric.

Findings: All transfer pathways in ECE increased in complexity by 84% on average. We found Computer Engineering to be a much less supported transfer pathway throughout the state's community college system compared to Electrical Engineering. Moreover, we found considerable variation in the community college system, raising concerns of consistency across partnerships in the state's system. Other programs can adopt the approach presented here to evaluate the complexity of their curricula.

Index Terms—Curricular complexity, descriptive statistics, engineering curriculum, organizational change, transfer students.

I. INTRODUCTION

CURRICULAR change has been discussed as a mechanism to attract underrepresented students to engineering [1], but the authors propose that despite intentions to broaden participation, ironically, less attention is paid to the impacts of wholesale curriculum changes on students at the margins—those who follow nontraditional pathways, including vertical transfer students (i.e., students beginning at a community college). In particular, this article focuses on how curricular changes may disrupt the existing policies concerning institutional partnerships, such as articulation agreements that outline transfer policies between four-year and two-year institutions.

This article examines the effect of a large curricular change within a four-year institution as it collides with and influences articulation agreements and associated institutional transfer policies for vertical transfer pathways, an unintended result of a National Science Foundation (NSF) program aimed at Revolutionizing Engineering Departments (RED) [2]. The three overarching goals of the curriculum change initiative included: 1) bringing a more diverse group of students into the department; 2) expanding student choice in the curriculum; and 3) encouraging a broader range of careers [3]. A necessary component of accomplishing the second goal, expanding student choice, was consolidating the essential knowledge of Electrical and Computer Engineering (ECE) into a smaller set of courses, thereby allowing students to engage in electives both inside and outside of the department. This redesign resulted in a set of eight highly connected courses unique to the institution. However, the uniqueness of the courses introduced a new problem—how do the new courses interface with existing agreements and established degree pathways with the state community colleges? In other words, how are ECE transfer student pathways affected by the large-scale programmatic change?

II. RESEARCH AIMS

This article focuses on the effects of large-scale curricular change on future transfer students in a Mid-Atlantic university's ECE department, which was implementing a \$2M grant funded by the NSF to revolutionize its curriculum. The department created a new set of eight courses unique to the institution required of all students enrolled in any of the department's majors, regardless of their matriculation path as

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David Reeping is with the Bradley Department of Electrical and Computer Engineering, Virginia Tech, Blacksburg, VA 24060 USA (e-mail: dreeping@vt.edu).

Dustin M. Grote is with the School of Education, College of Liberal Arts and Human Sciences, Virginia Tech, Blacksburg, VA 24060 USA (e-mail: dustg87@vt.edu).

David B. Knight is with the Department of Engineering Education, Virginia Tech, Blacksburg, VA 24060 USA (e-mail: dbknight@vt.edu).

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first-time-in-college (FTIC) or transfer. The curricular change was made with the intent to increase alignment between key concepts in the curriculum such that students experience integrated learning across sets of courses taken concurrently. This adjustment was executed through prerequisite and co-requisite structures placed on the new courses to form cohorts.

Moreover, the change aimed to broaden the participation of traditionally underrepresented groups in the discipline. Although ECE collectively appears to attract Black students, Hispanic men, and Asian men [4], the field is strikingly homogenized by gender. To illustrate, Electrical Engineering (EE) was the third most popular engineering discipline in 2018—comprising 10.1% of all bachelor's degrees awarded—yet, women earned only 14.2% of those EE degrees [5]. Computer Engineering (CpE) was the seventh most popular with 5.8% of all awarded bachelor's degrees, but only 13.3% of CpE degree recipients were women in 2018 [5]. The curricular change intends to enable students to recognize and explore the breadth of the field and provide opportunities for minoritized students to see how their interests may fit into ECE, supported by others in their cohort.

Cohort-style curricular structures are typically designed for students who enter the curriculum in their first year. Therefore, this work fills a notable gap in the literature and considers it imperative to evaluate how holistic curricular changes within four-year institutions may affect transfer student pathways to engineering degrees. The objective of this work is to present a comprehensive analysis of the potential effects of programmatic change on the curricular complexity faced by future transfer students, acknowledging that these challenges are compounded by an information gap between the four-year institution and the affected community colleges. Moreover, the analyses also show inconsistency in academic plans across community colleges by uncovering extremely different pathways to the bachelor's degree, despite each community college falling within the same system. Our analysis demonstrates how the entire system—internal and external to a department—should be considered when designing and making substantial changes to curricula in ECE and beyond because it could have varied impacts on students' degree progression.

III. LITERATURE REVIEW AND THEORETICAL FRAMING

This review first presents the model of an academic plan to situate the study—and studies like it—in the broader higher education literature. Considerations for transfer students are explained next to outline policies that establish pathways to four-year institutions. Finally, the metric used to quantify those pathways and enable comparisons between pathways in this study is provided to close the literature review.

A. “Academic Plan Model” as Theoretical Frame

This study was situated in the Academic Plan model by Lattuca and Stark [6] and focuses on the potential blind spot of the linkages of the community college system and transfer pathways with an academic plan when a four-year institution engages in curriculum reform (shown in Fig. 1). The model

casts academic planning within a sociocultural context, identifying how various internal and external forces influence, shape, and are impacted by the construction of academic plans.

Designing curricula and constructing academic plans are multifaceted processes involving several interconnected elements: 1) purposes; 2) content; 3) sequence; 4) learners; 5) instructional processes; 6) instructional resources; 7) evaluation; and 8) adjustment [6]. Ideally, considerations of the education benefits for student learning and well-conceived instructional rationales are at the forefront of decision-making processes for designing and arranging courses in an academic plan.

Curriculum design varies across academic disciplines, and engineering is uniquely positioned across field type, functioning both as a field with foundational science roots and also as a professional field [6]. Science curricula tend to be characterized by a series of courses that build upon one another conceptually. On the other hand, curricula in professional fields tend to include experiences focused on professional skill development and often include a field experience, internship, or capstone class that integrates students' learning across disparate courses. Engineering tends to bridge both sequential and parallel curricular structures, which makes it highly sequential, especially in the early years, with an integrated experience toward the end of the plan. These structures are complicated by the variation in the introductory engineering course content (see [7]), which can depend upon how students matriculate into their major (see [8]). Programs in ECE are particularly tricky from a curricular perspective as the field has undergone significant expansion, evidenced by its several highly specialized subfields [9]. From a policy perspective, programs rely on mechanisms such as prerequisite and co-requisite courses to enact course sequencing for students so that students intentionally progress through an academic plan. Thus, designing integrated first-year and second-year academic plans that expose students to the multiple facets of the field can be challenging.

As demonstrated in Fig. 1, academic planning, particularly, the selection and sequencing of content in engineering bachelor's degree programs, is iterative and occurs primarily within the academic department or discipline at the four-year institution. Consequently, changes in the content and sequence of curricula are usually shaped with the “majority student” in mind, which for many four-year institutions that enroll large numbers of engineering bachelor's students are most likely to be traditional FTIC students [10]. As an external stakeholder to the academic plan, less attention has been paid to how community college transfer pathways are impacted by curriculum design and change. The majority of prior literature on curricula focused on transfer is organized around articulation agreements that seek alignment with the existing curricula—it has not discussed the curriculum reform process.

B. Transfer Processes and Articulation in the Academic Plan

Community colleges are recognized as stakeholders in the four-year institution's academic plan via policies called articulation agreements. A primary aim of articulation agreements

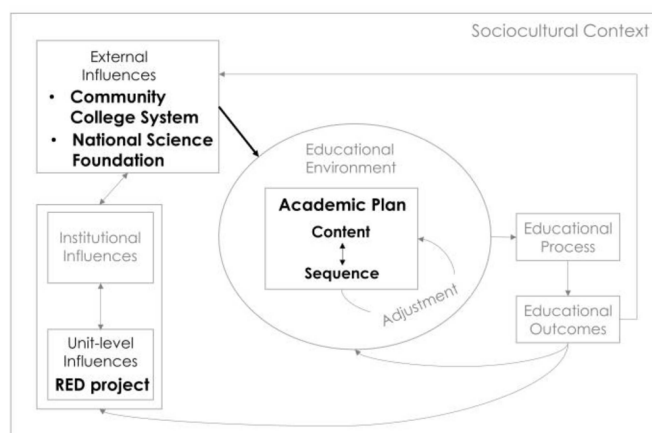


Fig. 1. Situating the study in the model of academic plans in context focusing on the blind spot of the external influence of the community college system on the academic plan. Only relevant constructs are shown, see [6] for full model.

between two-year and four-year institutions is to align curricular pathways for students seeking to complete bachelor's degrees via vertical transfer. Although articulation agreements between institutions have existed since the early 1900s [11], state involvement has grown substantially in the past 30 years to streamline the transfer of coursework processes at a system level through the implementation of statewide agreements between public institutions [11]–[15]. Most agreements focus on the preservation of credits for students who are able to transfer [16]. The following are commonly included elements of articulation policies that aim to streamline course transfer: 1) common general education package; 2) common lower division premajor and early-major pathways; 3) credit applicability; 4) students granted junior status upon transfer; 5) associate/bachelor's degree credit limits; and 6) acceptance policy for upper division courses [12]. If the four-year curriculum shifts, there can be intended and unintended consequences for many of these agreed-upon elements for transfer students.

Preserving credits across institutions via articulation agreements is particularly critical in engineering because of the sequential nature of the curriculum [17]. In a close examination of a statewide articulation initiative in Illinois, Skattum and Mirman [17] described the initiative's purpose was to establish “groupings of courses that students should be taking at each institution to ensure that, upon transfer, the taken courses will apply at the universities and the proper prerequisites will be fulfilled.” (pg. 9.332.2) Ensuring that courses taken at a community college apply toward students' degree and fulfill proper prerequisite requirements for upper level courses within university engineering programs is often established by including pre-engineering programs in articulation agreements [18]. Doing so formalizes partnerships between faculty at the two-year and four-year institutions to agree upon a subset of pre-engineering courses with course content that meets ABET criteria (i.e., accreditation organization for engineering and technology programs) [19] and ensures alignment of curricula. Instances where no articulation agreement exists, or when the structures of the agreement lack a specific pre-engineering curriculum that is guaranteed to transfer and

fulfill necessary prerequisite courses at the university, may be detrimental to students' timely progress to complete an engineering degree. Rosenbaum *et al.* [20] claimed community college students are more likely to succeed in highly structured community college programs; the authors contend the hypothesis in [20] would apply to well-supported, clearly structured transfer student pathways as well.

A notable gap in the literature exists on how—and when—articulation agreements adapt to large-scale curricular changes made at partner four-year institutions. These agreements are often static, irregularly updated, with substantive changes delayed or altogether halted by bureaucratic processes at each institution [11], [14], [21]. Even in cases where articulation agreements are routinely updated between institutions, few readily address modifications in policies with respect to course sequencing. Articulation policies typically specify courses, or packages of courses, taken at the community college that will be guaranteed to transfer to a four-year institution [21]. However, the policies often lack nuances to manage the modification of requirements at the four-year institution. These requirements, i.e., relationships between prerequisites and co-requisites, and progress to a degree in engineering have received growing attention in [22], including for transfer pathways [23]. Recent efforts in the literature have attempted to quantify the prerequisite and co-requisite structures, bringing about the *curricular complexity metric*.

C. Curricular Complexity Metric

A relatively new curricular complexity metric created by Heileman *et al.* [22] aims to quantify required course sequences within the curriculum. It is composed of two pieces, structural complexity (a measure of requisite structure interconnectivity) and instructional complexity (e.g., course pass/fail rates). This article discusses its design and operationalization in subsequent sections, focusing on *structural complexity*. The structural complexity metric has already been used in a few studies examining engineering curricula. Slim [24] and Hickman [25] conducted simulations for FTIC students using the curricular complexity framework and found structural complexity to relate inversely to completion rates. To validate the metric beyond a simulation context, Slim [24] compared the sequence of courses taken by students with high final grade-point averages (above 3.0) versus students with low grade-point averages (below 3.0) from the University of New Mexico's EE program and found that course sequence differed between the two groups and seemed to have an influence on progress to degree. Heileman *et al.* [22] conducted more simulation analyses that provide further evidence of structural complexity inversely relating to time to degree. Another study found that structural complexity varied across engineering disciplines and correlated with time-to-degree for FTIC students and for two-year/three-year time-to-degree for transfer students [23]. That study suggested ways to improve the tool to better address nuance in curriculum complexity that transfer students experience as they transition to four-year institutions.

As demonstrated in this article, the curricular complexity tool provides a method for quantifying the impacts of

curricular change on community college transfer student pathways. Although the curriculum revision under investigation in this article aimed at dismantling the existing rigid structures and rebuilding a more inclusive curriculum, such changes create new challenges for the transfer student population. These shifts create an unfortunate paradox—positive intentions of changing four-year curricula could have negative implications for some of the most vulnerable student populations.

IV. DATA AND METHODS

Transfer pathways into the department before and after the curricular change at the four-year institution were evaluated quantitatively. Plans of study for EE and CpE degrees at the receiving institution and engineering plans of study from 12 sending community colleges were purposefully sampled based on transfer student enrollments to comprise an evaluative case study. The prerequisite chains from the collected plans of the study were then entered into the curricular analytics tool [22].

A. Context of the Study and Researcher Positionalities

This study was conducted at a large mid-Atlantic institution in an ECE department during a transition period to a new program structure. The curriculum change was initiated, in part, to unite EE and CpE, two disciplines housed within the same department that historically divided faculty research areas [26]. The division was likely a product of EE's "(dis)integration" as a field described by Jesiek and Jamieson [9]—the fracturing of a field into more and more specializations.

Another goal of the curricular change was to broaden the participation of students in the department because of the relative homogeneity of the two programs along with racial and gender characteristics. Now, the disciplinary interrelations are codified in the plans of study for the department's majors, allowing students more flexibility to explore their interests that normally would not "fit in" with the department's norms.

The first author was formerly a Graduate Research Assistant on the curricular change project at the time of conducting the analyses and is now the Postdoctoral Associate who assists with the evaluation of the project—including the articulation plan for the community colleges—and teaches one of the new courses. At the time of the analyses, the second author was a Graduate Research Assistant on a related but independent project in a separate department concerned with enhancing transfer pathways for engineering community college students in collaboration with the two largest feeder community colleges. The third author is a co-PI on the latter project.

A quantitative approach to this work was chosen because a measure of the interconnectivity of a curriculum was desired and, by association, the freedom students have in choosing their own path through the curriculum could be assessed. The measure enabled the changes to the curriculum and their effect on advancing the RED project goals to be summarized using an established metric. Because this work was done to forecast the possible impacts on students, the authors made use of available data to perform the analyses.

The curricular analytics approach by Heileman *et al.* [22] was chosen considering their measure of structural complexity

has practical meaning in proxying a curriculum's completion rate [23]–[25]. If the complexity of the curriculum had increased, the completion rate would be predicted to decrease. The situation will be exacerbated for transfer students if they lose more credits than expected because of the new courses. Credit loss is an indicator of a decrease in the likelihood of graduation [27], so identifying potential interventions to support transfer students early would be ideal. This work served as a piece of data-driven advocacy to advance the conversation on transfer students in the project. The design aligns with the authors' values regarding such issues for the research community.

B. Data Collection

Data were acquired on all currently enrolled transfer students in the department during Fall 2018 ($N = 122$), who brought in a total of 5044 credits from 23 different institutions. Nine institutions were dropped from the analyses for three reasons: 1) only one student came into the department from the institution; 2) the institution was not a community college; or 3) the community college did not have a prescribed sequence of courses in engineering. The remaining 12 community colleges were then included in the sample—representing each main region in the state, serving heterogeneous student populations.

Plans of study reflecting the recommended curriculum both before and after the change were collected from the ECE department at the large Mid-Atlantic University. Additionally, two-year plans of study from the 12 community colleges were sampled from each institution's catalog for the 2018–2019 academic year. In total, 24 plans of study (12 for EE and 12 for CpE) from each community college were analyzed for this study. The general EE and CpE plans of study from the four-year institution's website were also collected to concatenate them with each community college plan of study.

C. Analysis

The impact of the curricular change was explored using the curricular analytics tool developed by Heileman *et al.* [22], which quantifies the requisite structures in a curriculum with a structural complexity metric. The structural complexity of the curriculum is composed of two measurements, the blocking factor and delay factor. The *blocking factor* of a course is the total number of courses in a prerequisite chain that a student is "blocked" from completing until that course is successfully completed. The *delay factor* is the number of courses in the longest prerequisite chain flowing through the course. Summing the blocking factor and delay factors for a course yields the course's *cruciality*. The calculation of a course's cruciality for the gray shaded course is shown in Fig. 2.

The structural complexity of the curriculum is found by adding all the course cruciality values together for an entire curriculum. Structurally complex curricula contain several long prerequisite chains and potentially co-requisite structures. Courses with high crucialities can be bottlenecks to student progress in the curriculum.

Transfer student pathways before and after the curricular change were generated by incorporating the community

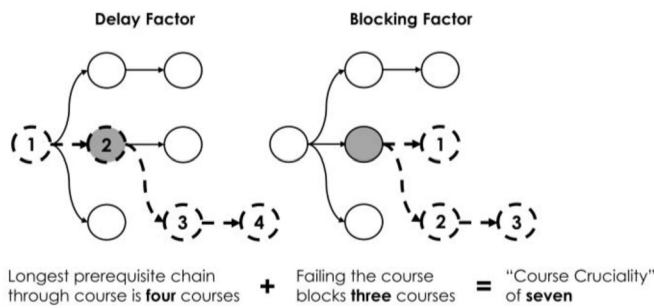


Fig. 2. Example calculation of a course's cruciality, for the gray shaded course. Cruciality is made up the course's delay factor and its blocking factor.

colleges' plans of study with the old and new ECE plans of study, respectively. Each consolidated plan of study combines the list of required courses for students to obtain an Associate of Science (AS) degree in engineering with required courses to complete either a Bachelor of Science (BS) degree in EE or in CpE at the Mid-Atlantic University. Where students were provided an AS degree pathway that specialized in EE or CpE, that course pathway was used. Where a specialized pathway was not explicit, the AS general engineering degree courses were used. The authors assumed students would get credit for general education courses taken at the community college but would need to enroll in the new eight courses regardless of which ECE courses they took at the community college. This assumption is possible because the new and old courses have no precise mapping to one another, so transfer students would have to enroll in the entire sequence of courses at the four-year institution. The process of consolidating the plans of the study yielded 24 pathways, 12 for EE and 12 for CpE.

The structural complexities for all transfer pathways were calculated and compared across the two majors in the department. Differences between the structural complexities before and after the change for all transfer pathways were calculated. A detailed analysis of transfer pathways after the curriculum change enabled us to identify problematic spots in the curriculum that could adversely affect a student's progress. The FTIC pathways were also calculated as a baseline measure.

D. Limitations

The bounds of this study must be discussed for us to draw appropriate conclusions of generalizability. Not all features of the academic plan [6] are examined here; this work focuses on "content" and "sequencing." Other departmental decisions may influence complexity, such as directives on when courses are offered during the academic year. Often a course may be offered in a semester that is different than what is specified on the plan of study—e.g., planned in Fall Sophomore but taken in Fall Junior because the course is offered every other year.

Moreover, this work is more applicable to programs with highly sequenced curricula. However, the authors contend the method is transferrable to virtually any evaluation of structural complexity, especially in determining the degree to which curricular change affects the curriculum's structural properties.

Community college pathways into the degrees were worst-case scenarios where students still needed to enroll in the new

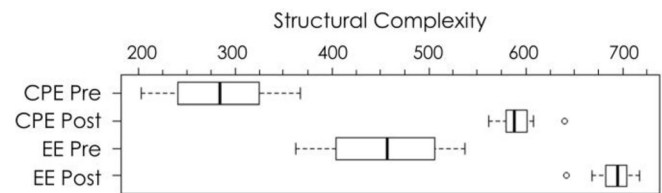


Fig. 3. Boxplot of structural complexity for CPE and EE pathways precurricular change and postcurricular change.

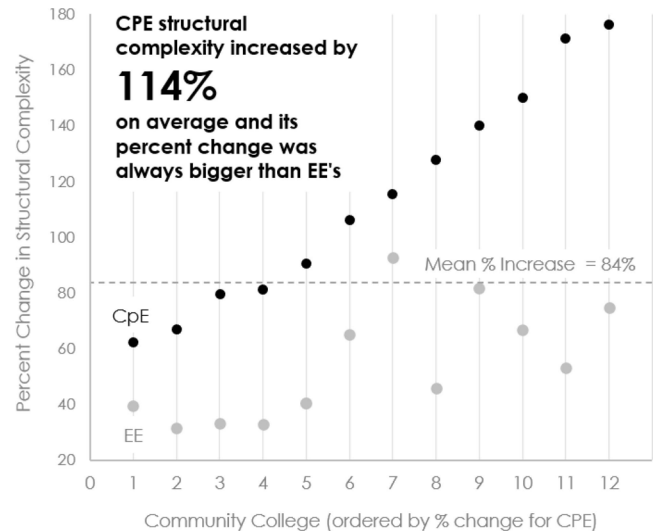


Fig. 4. Percent increase in structural complexity for transfer student pathways by community college, considerable variation was found between transfer pathways from community colleges in the same system.

courses for the 2022 plan of study. The "worst-case" analysis was done to be consistent with the curricular design requirement that no one-to-one mapping coursewise between the old and curriculum can be made. The authors admit the worst-case assumption was an analytical decision amenable to the current conceptualization of the curricular complexity tool, missing the nuance of bundling transfer credit for new courses.

Furthermore, the authors acknowledge the limitations of this tool for transfer students identified in prior research [22] and contended that the curricular complexity scores presented in this article may underestimate the magnitude of curricular complexity encountered by transfer students in this study's context. In particular, the difficulty of the courses—their "instructional complexity" [21], [27]—are not considered because simulating student flow is not currently available.

V. RESULTS

Fig. 3 presents a boxplot of the structural complexity values. All 24 transfer pathways into the ECE program increased in structural complexity by 84% on average. The transfer pathways for EE were uniformly more structurally complex than CpE before and after the change. Also, the variation in transfer pathway complexity decreased greatly.

The results were disaggregated by CpE and EE pathways—which revealed considerable disparities. Fig. 4 shows the increase in structural complexity for the transfer pathways for each community college before and after the change. Each set

of two vertically aligned points corresponds to the two pathways from the community college programs—either CpE or EE. The vertical axis is the percent increase in structural complexity from before the curricular change. This concatenation provides a glimpse into the change in the complexity of the codified pathway from the community college to the four-year institution.

Stark increases in structural complexity were seen in CpE transfer pathways. For comparison, the FTIC pathway for CpE increased by 88% while transfer pathways increased by 114% on average, where EE increased by 33% and 55%, respectively.

Variation in structural complexity can also be seen. The community colleges in the sample have established partnerships with the four-year institution, so the variation is evidence of misalignment between the existing curricula and the demands of specific majors. In particular, the percent-change in structural complexity shows that curricular alignment between the community colleges and the four-year institution with CpE is not as consistent as with EE pathways in this context. For example, CpE pathways from institutions 10, 11, or 12 where the structural complexity increased by more than 150% will face the most structural issues, and fewer students may matriculate.

VI. DISCUSSION AND IMPLICATIONS

The increase in complexity following curricular reform can be attributed to three factors, which introduces a paradox with the “sequencing” intentionality in the academic plan (i.e., [6]). First, the courses are all more purposefully interrelated to bridge the gaps between EE and CpE faculty and encourage communication across courses—this change yielded more coherent “purposes” in the academic plan. Second, the curriculum revision consolidated the required preliminary courses for all majors into a set of courses taken everyone, regardless of their intended major. Third, the required courses have all been relocated to the first two years of the program to encourage a cohort model with all students taking the same classes—encouraging social integration (see [29]) between the “learners” in the academic plan. In contrast, the prior version of the curriculum allowed students to delay taking a required course until their senior year. For example, an EE student could delay “Introduction to Computer Engineering” because it does not serve as a prerequisite for any of their specialized coursework. This strict alignment in the second year is a potential explanation in the reduced variance in structural complexity in the “post-change” pathways.

Moreover, this work demonstrates that prerequisite structures for a cohort model yield higher structural complexities. However, it is unknown how an intentional cohort model mitigates the negative relationship between structural complexity and completion rates (see [24], [25]). Heileman *et al.*'s [28] discussion of instructional complexity might benefit from considerations of cohort-enforced prerequisite chains to implement a more coherent academic plan, which is planned to be incorporated in future work to simulate four-year, five-year, and six-year completion rates.

The results of this work can have significance in both practice and research. The method of analysis was useful

in quantitatively articulating concerns regarding the curricular structure for all students, which could be applicable in broader ECE curricular discussions. Other EE and CpE programs can use the structural complexity measure to be more systematic about how changes to their curricula will affect both FTIC and transfer pathways into their programs by doing a pre/post analysis on the change in structural complexity. Moreover, faculty can use the tool to identify bottlenecks in their programs by examining courses with high crucialities. From a research perspective, this effort's approach extends the model of structural complexity by Heileman *et al.* [22] toward evaluating how curricular changes affect transfer student pathways. Future efforts will serve to continue extending the curricular complexity measure to incorporate transfer students' considerations, such as applying credit to certain courses, thereby aiding faculty with evaluating the effects of programmatic changes.

This work also has implications for articulation policy. First, institutional actors leading large-scale curricular change efforts at four-year institutions should consider the implications of those changes on articulation agreements with community college partners. Curricular overhauls are time intensive and resource intensive, both of which are constrained at community colleges, hindering the ability for two-year institutions to adjust curriculum quickly and adequately in response to changes at four-year partners. Additionally, four-year institutions must remember that two-year institutions have multiple transfer partners; changes should consider the competing demands of multiple institutional partners and transfer student pathways. Curricular change efforts should consider these unique challenges for students transferring from two-year institutions. For example, articulation policies could exempt those transfer students currently enrolled in a community college transfer program from the curriculum changes at the four-year institution, or obligate the four-year partner to create a “transfer experience” that bridges students into a new program. Finally, although most articulation policies involve aligning and guaranteeing the transfer of specific courses, or groups of courses, few also guarantee fulfillment of prerequisite and co-requisite requirements, which can have significant impacts on students' timely progress to degree.

VII. CONCLUSION

This work used a curricular analytics tool providing an approach to understand how large-scale programmatic changes can inadvertently affect a population of students. The authors found that the structural complexity of the curriculum for both EE and CpE transfer pathways increased dramatically. CpE was particularly troublesome, as the percent change in structural complexity scores from the same community college were uniformly greater than those for EE.

The methods used in this study enabled data-driven conversations—adoptable at other institutions—about the influence of large-scale curricular changes on transfer students. This work demonstrated why it is crucial for curriculum reform efforts within four-year institutions to consider potential differential influences on a range of stakeholders, including students who transfer into the program from a different

institution. Curricular change efforts with the best of intentions may result in unintended negative consequences.

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David Reeping (Member, IEEE) received the B.S. degree in engineering education (with a mathematics minor) from Ohio Northern University, Ada, OH, USA, in 2016, and the Ph.D. degree in engineering education from Virginia Tech, Blacksburg, VA, USA, in 2019.

He is currently a Postdoctoral Associate with the Bradley Department of Electrical and Computer Engineering, Virginia Tech. In his role, he assists with the department's Revolutionizing Engineering Department's grant and teaches a new course called Introduction to ECE Concepts. His main research interests include transfer student information asymmetries, threshold concepts in electrical and computer engineering, agent-based modeling of educational systems, and advancing quantitative and fully integrated mixed methods.

Dr. Reeping's recent awards and honors include a National Science Foundation Graduate Research Fellowship and his Ph.D.-granting department's Outstanding Dissertation Award.

Dustin M. Grote received the Bachelor of Science degree in psychology (emphasis: behavioral neuroscience) and the Bachelor of Arts degree in organizational communication from the University of Portland, Portland, OR, USA, in 2009, the Master of Arts degree in higher education and student affairs leadership from the University of Northern Colorado, Greeley, CO, USA, in 2015, and the Ph.D. degree in higher education research and policy from Virginia Tech, Blacksburg, VA, USA, in 2020.

He currently serves as a Postdoctoral Research Associate of engineering education with Virginia Tech. His research focuses on education policy to broaden participation in engineering, improving the community college transfer pathway to an engineering degree, curricular design and its impact on time to degree completion, and assessment and evaluation in higher education contexts.

David B. Knight received the B.S. and M.S. degrees from the University of Virginia, Charlottesville, VA, USA, in 2006 and 2009, respectively, the M.U.E.P. degree from the University of Virginia, and the Ph.D. degree in higher education from Pennsylvania State University, State College, PA, USA, in 2012.

He is an Associate Professor and an Assistant Department Head of Graduate Programs with the Department of Engineering Education, Virginia Tech, Blacksburg, VA, USA, where he is also the Director of Research of the Academy for Global Engineering, and is an affiliate faculty with the Higher Education Program. His research tends to be at the macro-scale, focused on a systems-level perspective of how engineering education can become more effective, efficient, and inclusive, tends to be data driven by leveraging large-scale institutional, state, or national data sets, and considers the intersection between policy and organizational contexts.