Development of Curricular Complexity Mapping Procedures to Support Student Success

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Abstract

The Curricular Complexity project, a collaborative effort between the University of Washington Tacoma (UWT) and Virginia Tech and funded by the National Science Foundation (NSF), investigates how quantitative curricular models correspond to STEM student success measures across different programs. Additionally, this project uses directed graphs known as “complexity maps” to model prerequisite structures within STEM majors, identifying critical gateway courses, blocking sequences, and structural delays that influence student progression and degree completion.

Our goal is to assess curricular complexity across different majors at the institution both quantitatively with complexity measures, and qualitatively with curricular map visualizations. The maps help visualize major options, identify hidden barriers such as critical gateway courses and restrictive prerequisite chains, and explore meaningful academic routes. Long term this data will be paired with student GPA and program completion rates to better understand the relationship with student pathways.

In this paper we share the results of curricular mappings for several STEM majors at the institution. Faculty and advisors have also used complexity maps not only to support students in making confident, informed major choices and improve advising conversations, but to identify areas where curricula can be restructured to reduce delays in degree progress, simplify prerequisite sequences, and make STEM pathways more accessible.

Introduction

Curricular pathways have been an area of curiosity in postsecondary education for many years as researchers have tried to identify what may contribute to student success along their academic path. While earlier work has acknowledged the role of curricular structure, this study explores *complexity maps* as a visual approach to making these structures accessible to students and advisors [1]. Prior research highlights the importance of program structure, course sequencing, and curricular complexity in shaping persistence, achievement, and degree completion among students. Navigational challenges such as prerequisite networks and heavy program load are some factors that contribute to barriers that can block or delay students' progress towards graduation. The curricular complexity occurs in addition to other challenges for student completion of engineering degrees [2], [3], [4].

In response, a collaborative study between Virginia Tech and the University of Washington Tacoma (UWT) was launched to investigate program complexity of existing majors. Funded by the NSF, this project computed complexity measures and created directed graphs known as "*complexity maps*" for STEM majors. A simple example of a complexity map is shown in Figure 1 for a few mathematics courses. Complexity measures and mapping tools help identify critical gateway courses, blocking sequences, and delays that can affect student progression for each major.

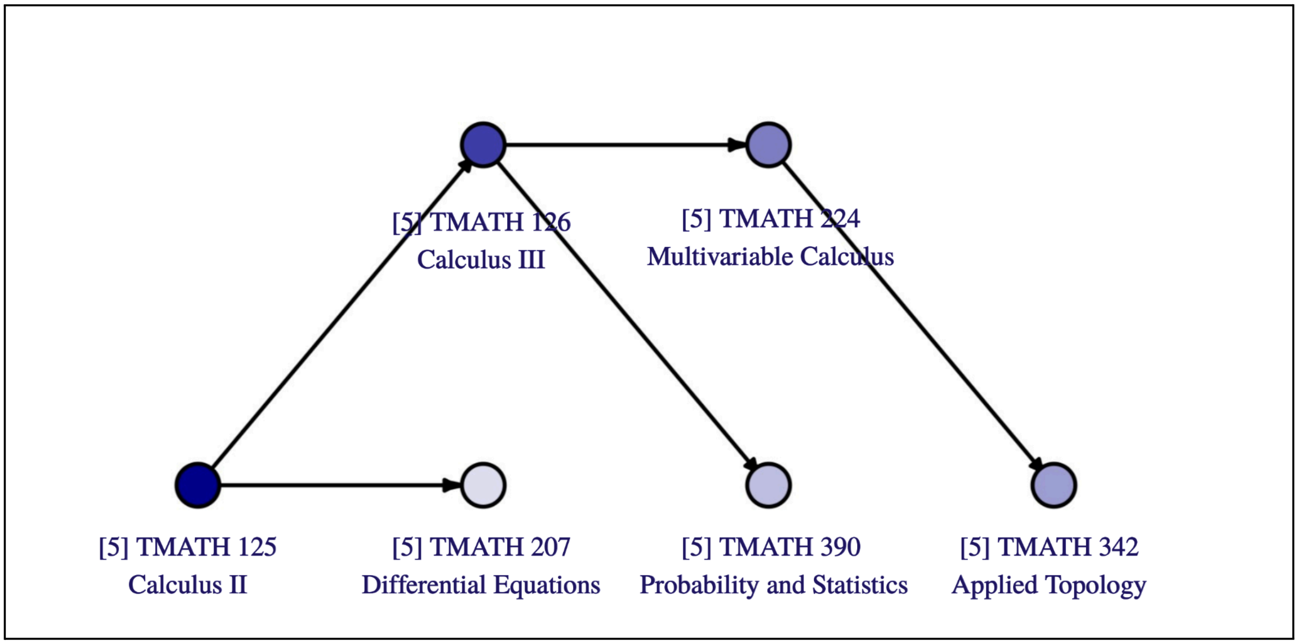

Figure 1. Overview of the complexity map visualization process.

The maps help establish key decision moments, including gateway courses and blocking sequences, that represent potential barriers to on-time graduation. Complexity measures can be computed for every course required by the major and is the outcome of two factors: the blocking factor and the delay factor.

The **blocking factor** calculates how many future courses are dependent on a given course as determined by prerequisites. For example, if TMATH 126 (Calculus III) is a prerequisite for three later courses, it has a blocking factor of three. Note many curricula have prerequisite "chains" like TMATH 344 (Fundamentals of Geometry) requiring TMATH 224 (Multivariable Calculus) which requires TMATH 126 (Calculus III). The prerequisites for TMATH 344 do not explicitly list TMATH 126 but we count TMATH 344 as a blocked class when computing the blocking factor for TMATH 126.

The **delay factor** of a course captures the longest prerequisite chain a course is in. Given the interconnectedness of curriculum, a course may be part of several chained courses. For example, TMATH 126 (Calculus III) is in the prerequisite chain of four courses: TMATH 125 (Calculus II) - TMATH 126 (Calculus III) - TMATH 224 (Multivariable Calculus) - TMATH 342 (Applied Topology) as well as the prerequisite chain of three courses: TMATH 125 (Calculus II) - TMATH 126 (Calculus III) - TMATH 390 (Probability and Statistics in Engineering and Science). The delay factor captures the longest chain and thus for TMATH 126, the delay factor would be four.

The blocking factor and delay factor are added together to form the **course cruciality number**, which reflects how crucial a course is within the major. The total of these values across a program's courses forms the **complexity score**, which measures the major's overall structural difficulty.

Complexity maps help to visualize the structural features of STEM programs, offering a clearer understanding of the relationships between courses, prerequisites, and degree requirements. The nodes of the maps correspond to required courses in the program and the directed arrows indicate a prerequisite requirement. For example, in Figure 1, the arrow between TMATH 125 and TMATH 126 indicates that TMATH 125 is a prerequisite for TMATH 126. Additionally, we encode the course cruciality number on the map by coloring the nodes: darker nodes represent higher course cruciality numbers, and light nodes represent lower cruciality numbers.

By making the invisible structures of majors more transparent, complexity maps can simplify academic planning, reduce barriers to success, and promote greater equity. The ultimate goal is to reduce unnecessary complexity in degree programs, and address the barriers that disproportionately affect underrepresented students in STEM education. **In order to understand the maps' effects, we posed the following research question: How do complexity scores vary across different programs of study at one institution?**

Background

Early authors explored the philosophical nature of curriculum design [5]. More recently, STEM programs have started to analyze the way in which curricular reforms impact programs. Some studies tie the complexity of the programs to the quality and graduation rates [1], [6]. The broader focus has been on curricular reform applications, including understanding the most important pre-requisite courses [7]. A summary of the relevant literature in the space is shown in Table 1.

Table 1. Summary of the prior literature focused on curricular complexity.

Author/Citation	Year	Disciplines	Insights
Slim [7]	2014	STEM	Most crucial courses in the institution are all math courses.
Heileman et al. [1]	2019	Electrical Engineering	Higher quality engineering programs have lower complexity curricula. Studied at electrical engineering programs across several universities (top tier, mid tier, and bottom tier as determined by 2018 US News & World Report).
Grote et al. [6]	2020	Community Colleges	Curricular complexity correlates with graduation rates for first time college students at different time intervals. Curricular complexity does not necessarily correlate with graduation times for transfer students
DeRoccis et al. [8]	2021	Electrical Engineering	Confirmed a direct relationship between schedule complexity and time-to-graduation
Lionelle et al. [9]	2024	Computer Science	Degree complexity, blocking factor, and delay factor are all inversely related to the representation of women.
Present Work	**2025**	**STEM courses at a regional institution**	**Analysis of maps for different STEM programs**

Our work is unique in focusing first on STEM courses at a regional institution with high rates of community college transfer students. This complicated the complexity analysis since the program application process at the point of institution transfer was modeled separately from prior studies. We have included all engineering majors in our analysis.

Methods

There is a great deal of variability between majors and experiences between students that can affect the complexity number computations. We provide some details and motivation for our choices when constructing the curricular complexity tools and numbers for consistency across majors in this paper. Note that each of these choices can dramatically affect the complexity number reported.

- **Starting Point for Curriculum Mapping**
  Each curriculum was modeled to begin with either Precalculus (TMATH 120) or Precalculus II - Trigonometry (TMATH 116). This reflects the reality that a large proportion of students start their pathway at one of these two points of entry.
- **Entire Major Curriculum Included**
  Several majors list courses that are "prerequisite" for the major while other courses can be listed in the "core". Given the large variable usage of this division of courses across majors, we elected to include the complete curricular map from first year courses to the last year.
- **Application Courses and Major Access**
  Majors that required an application to continue with their program were given an artificial course we called "Application". Courses restricted to declared majors were designated as courses requiring the "Application" course . The prerequisites for the "Application" course were treated as the minimum required courses to apply for the major. Including this increased the BA in Computer Science from 60 to 194 which seems to be a more reasonable acknowledgment of the application process. However, the Electrical Engineering curriculum complexity number jumps from 457 to 612.
- **Verification of Course Requirements**
  To maintain logical consistency, we verified that all prerequisites for the "Application" course were also formally required for the major. This step ensured that the visualized curricular paths remained aligned with actual program plans and institutional policies.
- **Elective Pathways**
  Elective modeling was guided by the assumption that students would opt for the path of least resistance. Given that more than one elective option is available, we assumed that students chose the course that had the fewest or no prerequisites, reflecting a common strategy to minimize academic barriers.

In addition to the complexity number and maps created for each major, we report the average complexity per class. This additional measure was chosen to more easily compare majors with significantly different numbers of required classes. Note part of the reason for the high variability in course numbers is because of the variability in credits for each course. For example, all TMATH courses are 5 credits but TME 311 is 2 credits.

Data collection and Visualization

Step 0 - Selection of Majors and Programs of Study

We began by identifying the specific majors and academic programs to analyze. The focus was centered on institution-specific courses, with elective options considered for their potential influence on curriculum pathways.

Step 1 - Data Collection and Initial Structuring

Curriculum data were collected directly from institutional websites and organized into a structured spreadsheet format. At this stage, we also determined the appropriate curricular entry point for each program.

Step 2 - Data Verification

To ensure accuracy and consistency, all collected data were verified with program officials, institutional sources, and official course catalogs.

Step 3 - Code Execution

The selected data were then processed through custom code to generate initial visual representations of the curriculum.

Step 4 - Adjustment of Sequencing and Course Scheduling

We adjusted the term-by-term mapping of courses to enhance the visualizations clearer and easier to interpret, ensuring that they more accurately reflected a realistic student pathway.

Step 5 - Expert Review and Feedback

Finally, the visual outputs and foundational assumptions were reviewed in collaboration with faculty members and subject-matter experts to evaluate findings and support ongoing improvements.

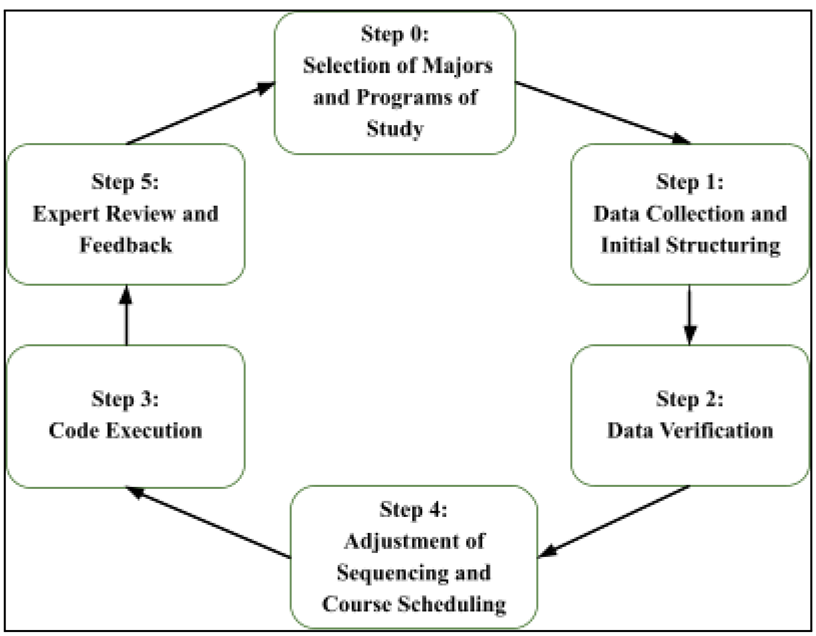

Figure 2: Data collection and Visualization Process

Results

Our research team analyzed seven programs in STEM majors. Initial investigations uncovered widely different structures and requirements for each major. For example, Electrical Engineering had significant course (8) admissions requirements for the major whereas the mathematics major had none, nor even an application requirement. This exploration informed the decisions provided in the Methods section.

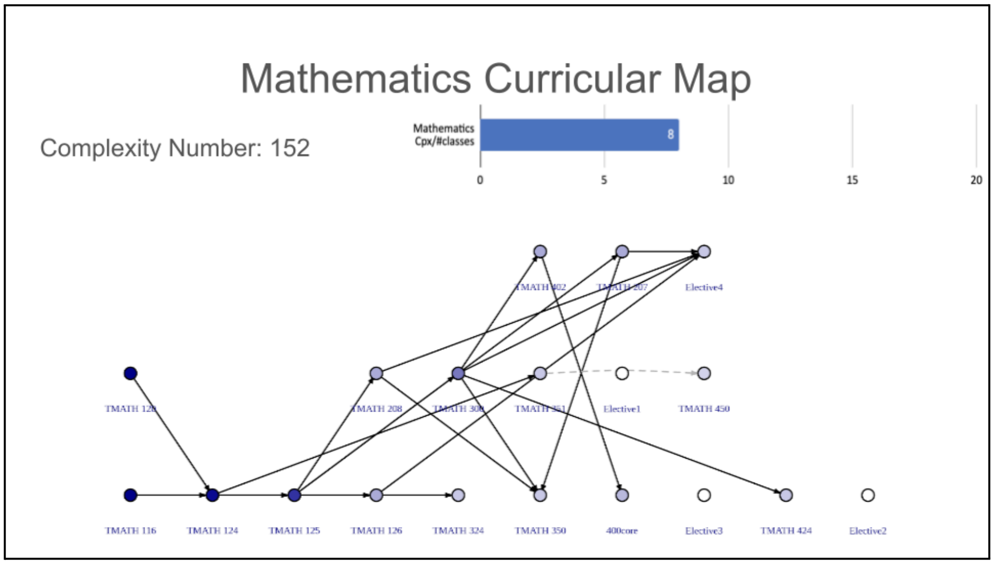

Figure 3. Curricular map for the mathematics curriculum. A bar graph at the top shows the average complexity per class as 8.

Figure 3 is the **Mathematics Curricular Map**, visualizing course progression and dependencies within a mathematics program. The "Complexity Number" of 152 quantifies the structural complexity of the curriculum as defined in the Introduction section.

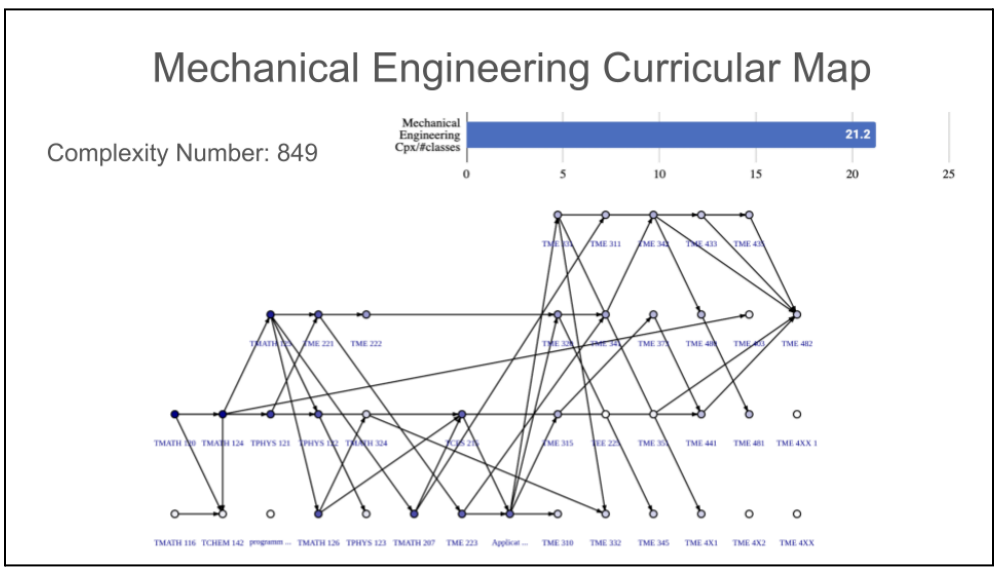

Figure 4. Curricular map for the mechanical engineering curriculum. A bar graph at the top shows the average complexity per class as 21.

Figure 4 presents a **Mechanical Engineering Curricular Map**, illustrating the sequence and interdependencies of courses within the major. The **Complexity Number of 849** reflects a dense and highly interconnected curriculum, demonstrating the intricate structure and progression required in mechanical engineering education.

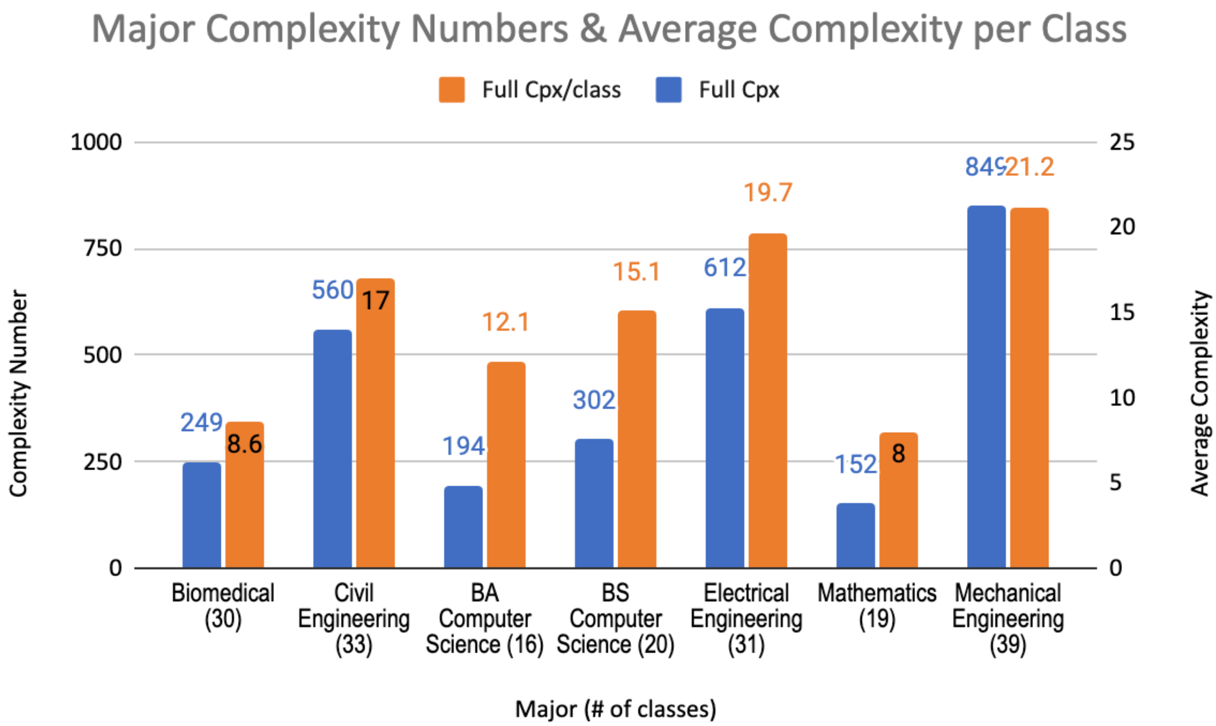

Figure 5. This bar chart compares the **Complexity Number** (in blue) and **Average Complexity per Class** (in orange) across various majors. Each major is listed along with its total number of classes.

Maps and analysis for all the STEM majors at the institution were then calculated and summarized in Figure 5. This bar chart compares the **Complexity Number** (in blue) and **Average Complexity per Class** (in orange) across various majors. Each major is listed along with its total number of classes. The results indicate that the mechanical engineering curriculum and electrical engineering curriculums are the most complex for students to navigated by either the average complexity per class or the overall complexity number.

Conclusions

After analysis of the program data we return to our research question, **RQ1: How do complexity scores vary across different programs of study?**

Our analysis showed a clear visible difference in complexity scores across majors. Programs with numerous required courses and prerequisites, tend to have significantly higher complexity scores. This suggests that students in these majors face more barriers in navigating their degree pathways.

Importantly, we found that delays to student progress often exist more at the course level than at the overall curriculum level. Each individual course, especially when it is a prerequisite, has the potential to act as a constraint.

There may be a trade-off between alternative pathways and lower complexity in a curriculum that are offset by the sequence in which students might choose to take classes. In other words, students might take classes in an order that is not ideal.

Furthermore, our findings indicate that the complexity metric struggles to fully capture alternative pathways within degree programs. For example, while Mathematics may offer several options for course sequences, these alternatives are not as common, or perhaps not as accessible as they could be. This suggests an opportunity for institutions to intentionally design and promote more practical alternative pathways.

Finally, there appears to be a trade-off between curricular flexibility and complexity. A curriculum may appear less complex if it allows more course options, but this can be balanced out by the order in which students choose to take courses. In such cases, students may unknowingly follow non-ideal sequences that increase their time to earn a degree or risk higher withdrawal rates.

Acknowledgments

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