Equitable Attainment of Engineering Degrees: A Tri-University Study & Improvement Effort

Raian Islam, The University of Arizona

Raian Islam is a current Master's student and a Graduate Research Assistant in the Department of Electrical and Computer Engineering at The University of Arizona, Tucson, AZ, USA. She received her BSc. degree in Electrical and Electronic Engineering from Ahsanullah University of Science and Technology, Dhaka, Bangladesh, in 2019. Her current research interests include higher education data analytics, machine learning and photovoltaics.

Prof. Gregory L. Heileman, The University of Arizona

Gregory (Greg) L. Heileman currently serves as the Vice Provost for Undergraduate Education and Professor of Electrical and Computer Engineering at the University of Arizona, where he is responsible for facilitating collaboration across campus to strategically enhance quality and institutional capacity related to undergraduate programs and academic administration. Professor Heileman currently serves on the Executive Committee of AZTransfer, an organization that works across the system of higher education in the State of Arizona to ensure students have access to efficient, seamless, and simple ways to transfer from a community college to a university in Arizona. He serves on the board of the Association for Undergraduate Education at Research Universities, a consortium that brings together research university leaders with expertise in the theory and practice of undergraduate education and student success. In addition, he is a fellow at the John N. Gardner Institute for Excellence in Undergraduate Education. Professor Heileman's work on analytics related to student success has led to the development of a theory of curricular analytics that is now being used broadly across higher education in order to inform improvement efforts related to curricular efficiency, curricular equity, and student progression. A website facilitating access to curricular analytics tools is available at: CurricularAnalytics.org.

Kian G. Alavy, University of Arizona
David Ruiter, University of California, San Diego

Equitable Attainment of Engineering Degrees: A Tri-University Study & Improvement Effort (Work In Progress)

Raian Islam,† Kian G. Alavy,† Gregory L. Heileman,† David Ruiter,‡
Mitchell L. R. Walker II⋆

{raiani, alavy, heileman}@arizona.edu, druiter@ucsd.edu, mitchell.walker@coe.gatech.edu
†University of Arizona
‡University of California, San Diego
⋆Georgia Institute of Technology

Abstract

In this paper, we describe a work-in-progress study, involving three universities, that considers various factors related to more equitable attainment of engineering degrees. ”Equity” in this case, refers to students from all backgrounds having similar outcomes in terms of their ability to earn an engineering degree within four years. The need for an increasing supply of engineering graduates is well understood as a necessary component for sustaining innovative industrial growth, national security, and global competitiveness, among other areas of national need requiring engineering talent. In order to address these issues, this study design involves consideration of various instructional and structural complexity factors that may contribute to delays in student progression through engineering degree programs. The universities engaged in this work are the University of Arizona, the University of California, San Diego, and the Georgia Institute of Technology. The study was designed around three principles: (1) collaboration through task forces across multiple institutions, (2) disciplinary focus using an asset-based approach, and (3) a student-centered approach to improving engineering student success through curriculum and instruction, leading to reforms in service of equitable outcomes. The primary analyses revealed the large variability in curricular structure and student success outcomes within each of these disciplines. Faculty and administrators formed subcommittees according to these disciplines and were asked to look for best practices and potential barriers and to consider avenues of reform for their own programs according to curricular structure or instructional practices.

Introduction

The student success imperative in higher education is driven by the fact that earning a bachelor’s degree has become an increasingly important rung on the ladder of economic advancement. Unfortunately, however, across U.S. higher education, there are disparities in the rates at which low-income, first-generation, and certain minority populations are able to complete a bachelor's degree, as compared to the college-going population as a whole.[8] Cost of attendance and other barriers worsen the disparities in college graduation rates. Personal and academic reasons also cause delays in graduation, leading to additional costs and lost employment opportunities.[1,6,9] The likelihood of earning a degree also decreases with additional time in college, especially for vulnerable students. Thus, the "efficiency" of progress within particular degree programs provides an important measure related to equitable attainment.[11] Specifically, if some degree programs are inherently less efficient, and, therefore, more difficult to complete, they will be less likely to produce graduates from vulnerable student populations, perhaps constituting a structural inequity in higher education.

A key goal of the study described in this paper involves gaining a better understanding of the various factors that may lead to inequities in the attainment of engineering degrees. Because engineering programs often have some of the most complex curricula on a college campus, they tend to take more time to complete, thereby contributing to the disparities described above. The important questions are: how much of this complexity is inherently necessary, and are there better ways to manage the inherent complexity through improved curricular structures and instructional design? The study described here was designed to address these questions through a data-informed approach involving disciplinary experts located within the engineering departments at three major research universities. The most challenging aspects of this study involve organizing across multiple universities, each with their own histories and customs, creating conditions that might produce positive change within deeply entrenched disciplinary cultures, and sustaining this effort over time. This paper describes the change management practices that have been utilized as a part of this study, along with results to date.

Managing Change

Organizational change is one of the most difficult tasks to manage under any conditions, and the bureaucratic structure of universities makes programmatic change a particularly difficult situation. A change management model that roughly follows Kotter's change model was used to guide this study, aimed at encouraging university engineering departments to embrace change and improve programmatic improvements for equitable student success.[5] The specific steps being followed in this study are described next.

Creating Urgency. Engineering occupations are among the highest-paying and most prestigious in the U.S. labor market, but they are also some of the least diverse.[2] Not only does this point to social inequity, it actually serves to undermine the quality of engineered systems—solutions created by diverse engineering teams are simply better.[7,10] In support of creating a sense of urgency around the need to investigate programmatic change, "equity gaps" were provided showing the demographic discrepancies between state populations, university populations, and the populations within particular engineering colleges and departments. At the Georgia Institute of Technology, it was shown that engineering students have highest time-to-degree, and that underrepresented minorities (excluding black), black, and Pell-eligible students are disproportionately impacted (see Figure 1).

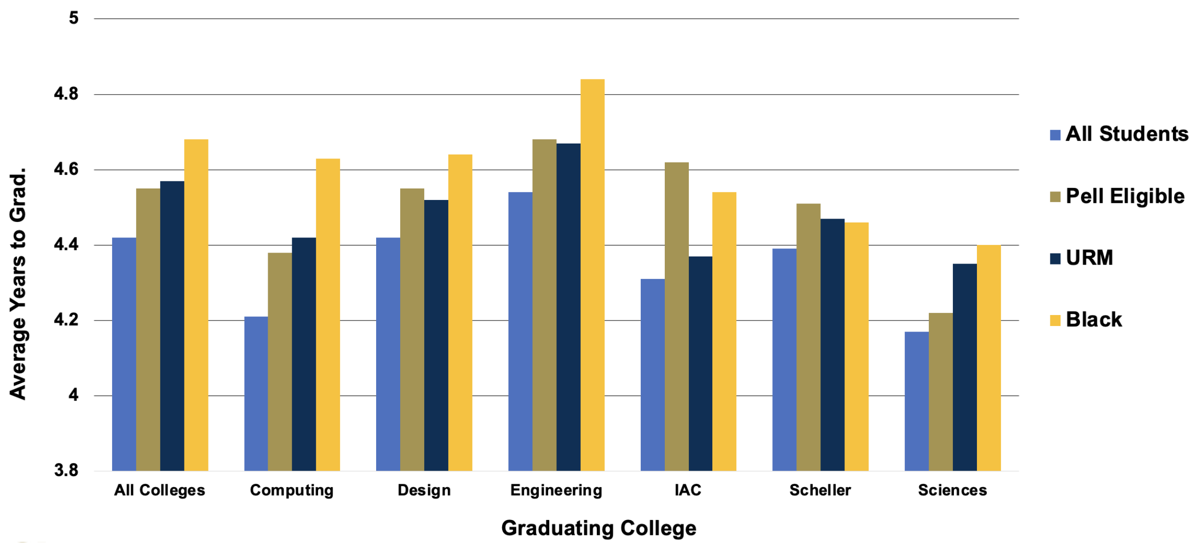


Figure 1: Time-to-degree, by college, for all first-time students starting at the Georgia Institute of Technology between 2012 and 2017.

Form Powerful Guiding Coalitions. Guiding coalitions are instrumental for successful change in higher education. This study involved multiple departments across universities, which posed significant organizational challenges to inform and influence decision-making around changes in complex engineering programs. The organizational structure that emerged over time in support of this effort is shown in Figure 2. The top of this figure involved three universities, with endorsements and support from top academic administrators, forming a collaboration committee to coordinate work across institutions. The committee established discipline-specific committees shown along the bottom of Figure 2 for five engineering disciplines, empowering them to suggest their own improvements. The collaboration committee worked to create initial analytics, launch the effort, and provide support for individual engineering colleges and departments.

Develop a Vision and Strategy. The overarching vision for this project involves the development of a framework for improving equity in engineering outcomes. The strategy involves developing discipline-specific best practices to improve curricular design patterns and instructional practices, leading to better learning outcomes and reduced time-to-degree. As part of the strategic approach to leverage the collective expertise of three public research institutions, initial data were collected and analyzed to compare/contrast curricular complexities, instructional design issues, and student success factors across the three participating schools. Each university initially performed different analyses in support of "jump-starting" the effort.

At the University of Arizona, the curricula of the five common engineering programs at the three universities were collected, along with the curricula from 17 other institutions with highly regarded engineering programs. A theory of curricular complexity has been developed that relates curricular structure to time-to-degree.[3] Based on that theoretical model, the structural complexities of these programs were analyzed and provided to each of the three institutions. (See Appendix A for an overview of structural complexity.) What is striking is the extreme variability in structural complexity values observed for a single engineering discipline at different universities, even

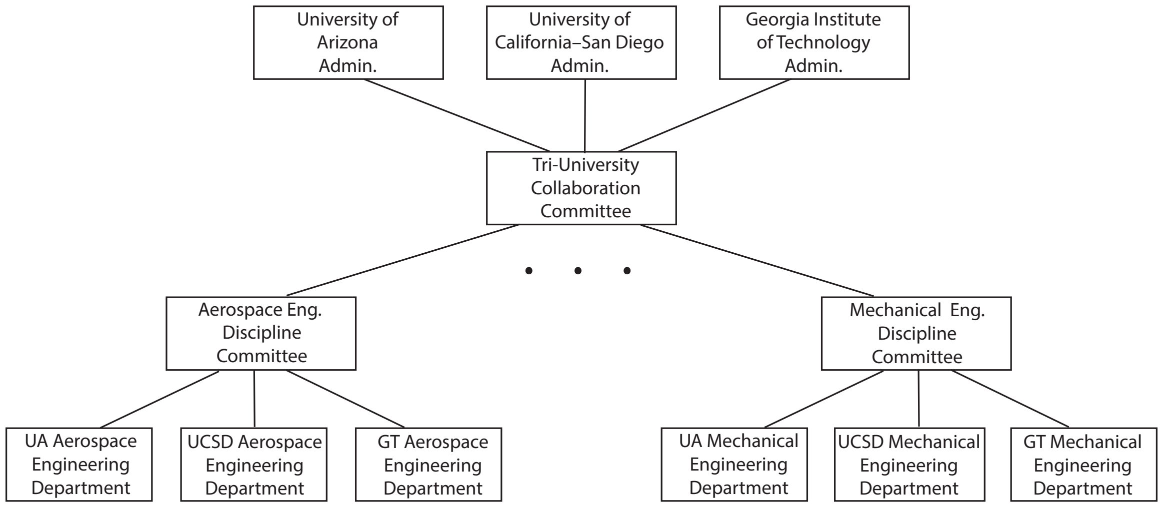


Figure 2: The organizational structures created to support this project.

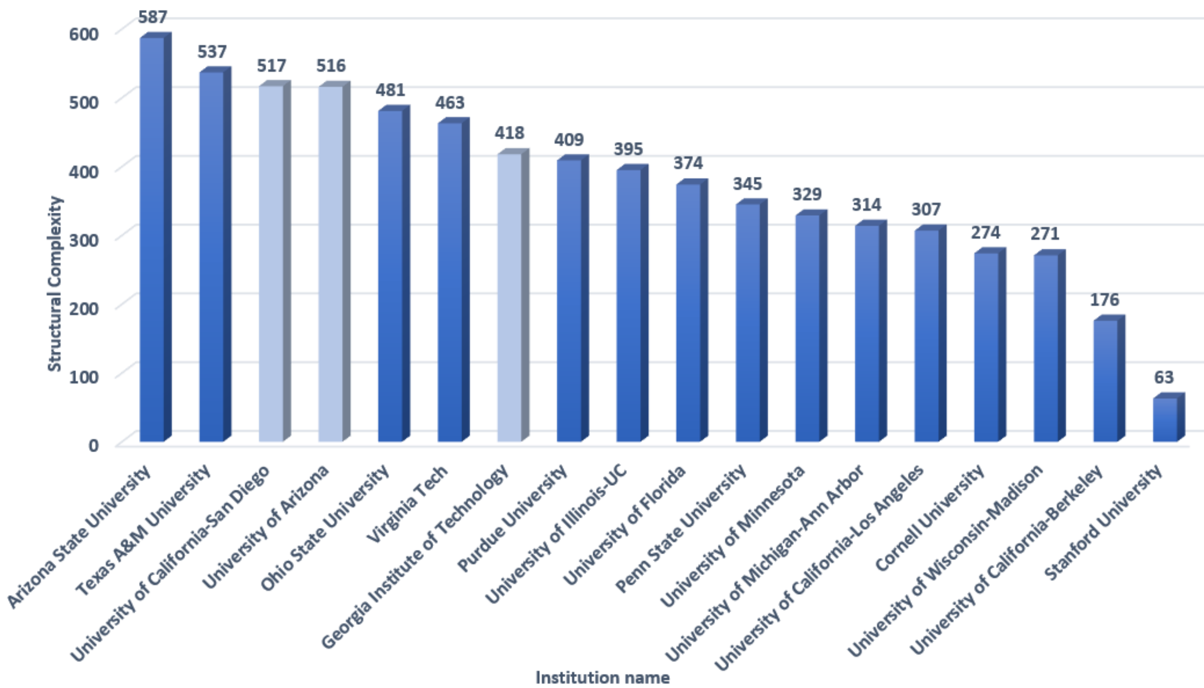
though many have identical accreditation standards (and therefore identical program-level learning outcomes). As an example, consider the histogram shown in Figure 3, where the structural complexities of the 18 aerospace engineering programs considered in this study are shown. The difference in complexity between the lowest and highest complexity schools is nearly ten-fold. Given that structural complexity directly impacts time-to-degree, a logical question to ask is this: do some of these curricular structures better serve students, leading to more equitable outcomes? This is a question each of the discipline-specific committees will consider. To support this work, similar histograms were created for all five engineering disciplines involved in the study. A box-and-whisker diagram showing the variabilities that exist within and between the programs at the different universities considered in this study to date is provided in Figure 3.

At the University of California, San Diego, the curricular complexity factors are confounded by the manner in which curricula are offered by the colleges at the institution. Each engineering discipline must consider seven different curricula due to the seven colleges offering their own general education programs that overlap with major courses. To aid this effort, the university created a Tableau dashboard that provides curricular metrics and a historical view of program curricula changes. The dashboard enables users to view a program's curricular complexity and perform what-if analyses for each college's curriculum.

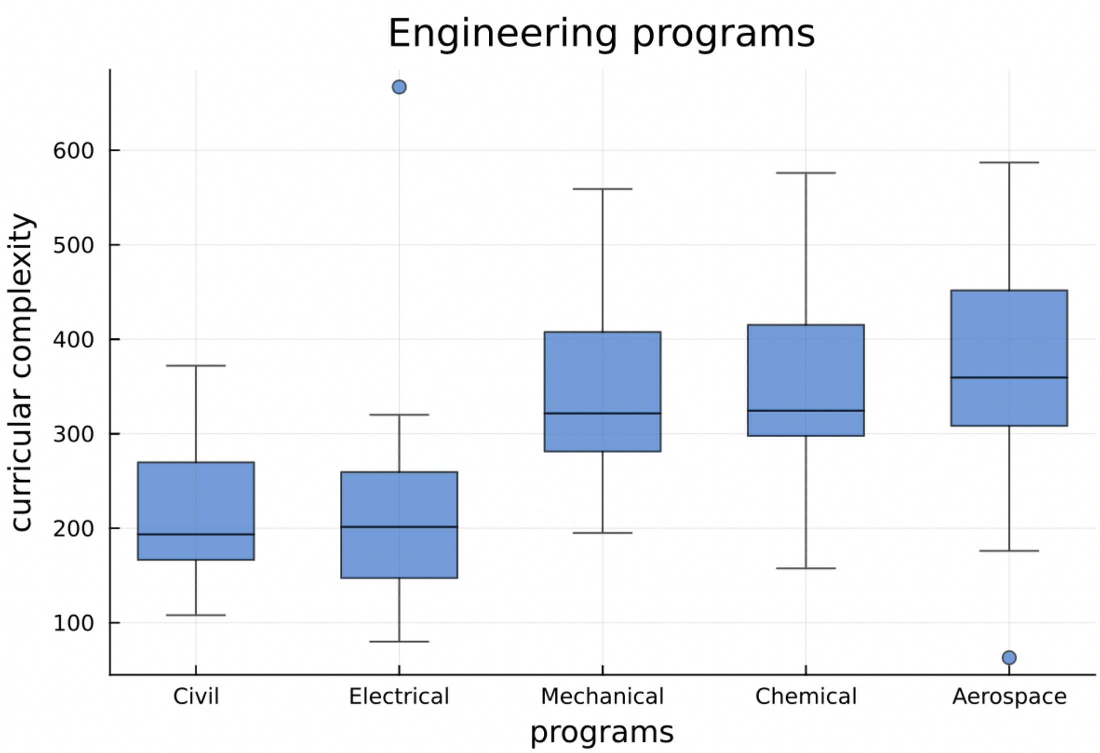
At the Georgia Institute of Technology, it was observed that the vast majority of students who do not take courses during summer terms are unlikely to graduate in four years. It was discovered that lower success rate courses are the ones that students take during the summer term to graduate on time (and in a number of cases, it is the same course in multiple programs). This analysis was repeated at the other two institutions involved in this study.

The analyses described above were shared among the institutions at the project kick-off. Furthermore, two initial research questions were posed:

- How do the structural complexities of curricular pathways differ among various top engineering (within and between) disciplines?



(a)



(b)

Figure 3: (a) The structural complexities of the 18 undergraduate aerospace engineering considered in this study, with the three participating schools highlighted. (b) The structural complexities of different undergraduate engineering programs, by discipline, were collected from 20 different universities. The dots in the figure correspond to outliers.

- What is the impact of incoming students' attributes on graduation rates over different periods of time?

Communicate the Vision. In order to convincingly communicate the vision and strategy for this change endeavor, the provosts/executive vice chancellor from the respective universities hosted a kick-off meeting involving engineering deans, department heads, and any other parties interested in this work. The importance of this work was clearly articulated, along with its relevance to the universities' missions and the national need. In addition, directions were provided to the disciplinary working groups.

Remove Obstacles. To support the work of busy department-level administrators and faculty in discipline-based committees, the tri-university collaboration committee established structures and processes, including a "data lift" at the college/university levels and ongoing analytics support from institutional research offices. A project manager was hired to manage meetings and project milestones associated with the committees in Figure 2.

Create Short-Term Wins and Consolidate Gains. Because motivation is a crucial element in sustaining change-related work, it was and will continue to be, important to create opportunities for short-term wins. Short-term wins were created by empowering faculty to lead and collaborate across peer institutions. Finding discipline-specific opportunities for student success across institutions could scale the work nationally.

Anchor the Change in the Culture. The equity-based framing and accompanying analytics have provided a different lens through which programs may view student success in engineering programs, and we have already seen this thinking begin to permeate student success discussions on campus. Going forward, as a part of the work of the committees involved in this study, it will be important to consider how positive changes will be institutionalized in the cultures of our institutions.

Discussion

In this paper, we described the current state of an ongoing tri-university study aimed at creating more equitable outcomes with regard to the attainment of engineering degrees. This work involved creating a new framing for considering equity in engineering programs, and has engaged faculty as change agents around one of the most fundamental elements of student success, namely the curricula that students must confront in order to earn engineering degrees. The study design described here was driven by the belief that changes supported by metrics that demonstrate student benefits are far more likely to be endorsed by faculty than those emanating as top-down dictates from administrators. Preliminary analyses and the current state of the study were shared, and future updates will consider the particular changes that resulted from this work, along with their impact on equitable student success outcomes in these engineering programs.

References

[1] V. Bocsi, T. Ceglédi, Z. Kocsis, K. E. Kovács, K. Kovács, A. Müller, K. Pallay, B. Éva Szabó, F. Szigeti, and D. A. Tóth. The discovery of the possible reasons for delayed graduation and dropout in the light of a qualitative research study. *Journal of Adult Learning, Knowledge and Innovation*, 3(1):27 – 38, 2019.

[2] E. Grieco and S. Deitz. Special report NSF 23-315: Diversity and STEM: Women, minorities, and persons with disabilities 2023. Technical report, National Science Foundation, National Center for Science and Engineering Statistics (NCSES), Alexandria, VA, 2023.

[3] G. L. Heileman, C. T. Abdallah, A. Slim, and M. Hickman. Curricular analytics: A framework for quantifying the impact of curricular reforms and pedagogical innovations. *www.arXiv.org*, arXiv:1811.09676 [cs.CY], 2018.

[4] G. L. Heileman, H. W. Free, O. Abar, and W. G. Thompson-Arjona. Curricular Analytics Toolbox, https://github.com/curricularanalytics/curricularanalytics.jl, 2019.

[5] J. P. Kotter. *Leading Change*. Harvard Business School Press, Boston, MA, 1996.

[6] G. D. Kuh, J. Kinzie, J. H. Schuh, and E. J. Whitt. *Student Success in College: Creating Conditions That Matter*. Jossey-Bass, San Francisco, CA, 2010.

[7] D. C. Mays. How diversity makes better engineering teams. *Journal AWWA*, 114(7):62–67, 2022.

[8] D. Riley. Rigor/us: Building boundaries and disciplining diversity with standards of merit. *Engineering Studies*, 9:1–17, 12 2017.

[9] V. Tinto. *Leaving College: Rethinking the Causes and Cures of Student Attrition*. University of Chicago Press, Chicago, IL, 2nd edition, 1987.

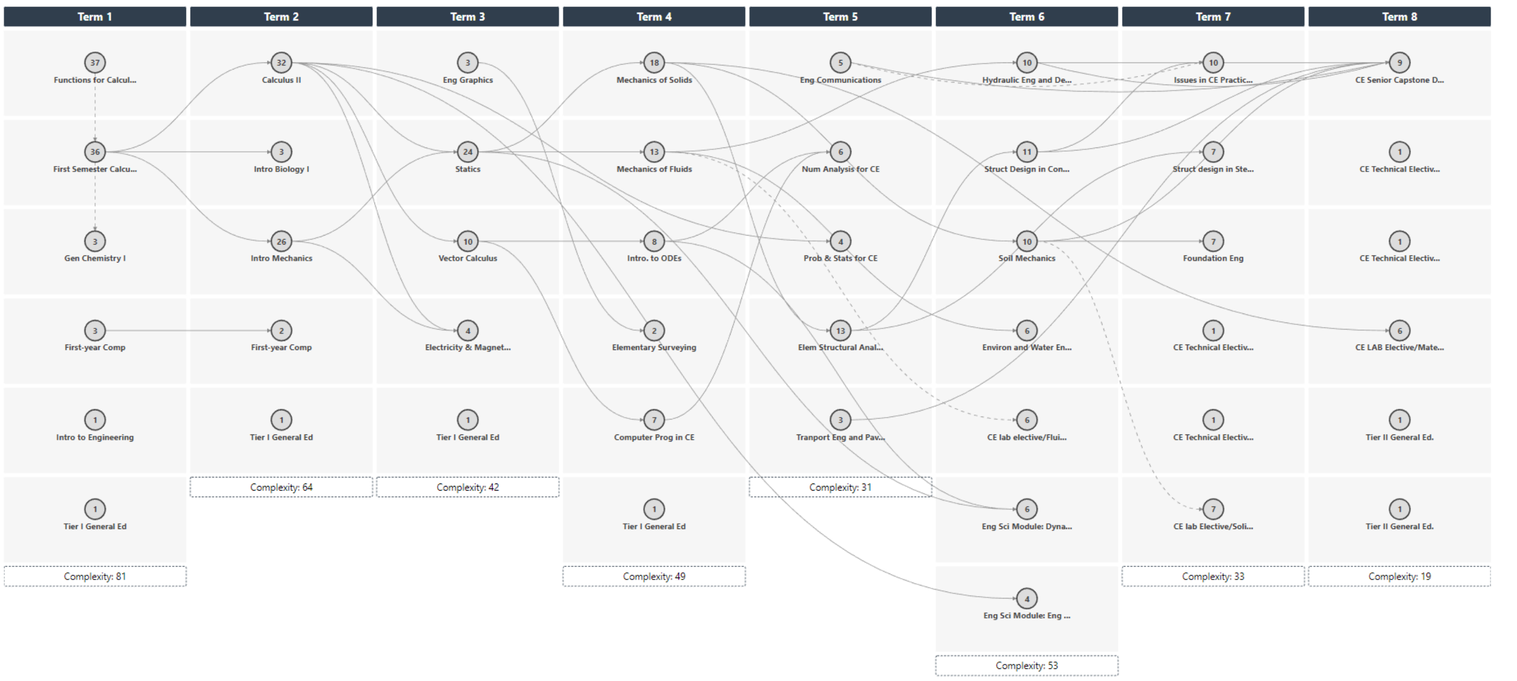
[10] P. Tourani, B. Adams, and A. Serebrenik. Code of conduct in open source projects. In *2017 IEEE 24th International Conference on Software Analysis, Evolution and Reengineering (SANER)*, pages 24–33. IEEE, 2017.

[11] J. Wigdahl, G. L. Heileman, A. Slim, and C. T. Abdallah. Curricular efficiency: What role does it play in student success? In *2014 ASEE Annual Conference & Exposition*, pages 24–344, 2014.

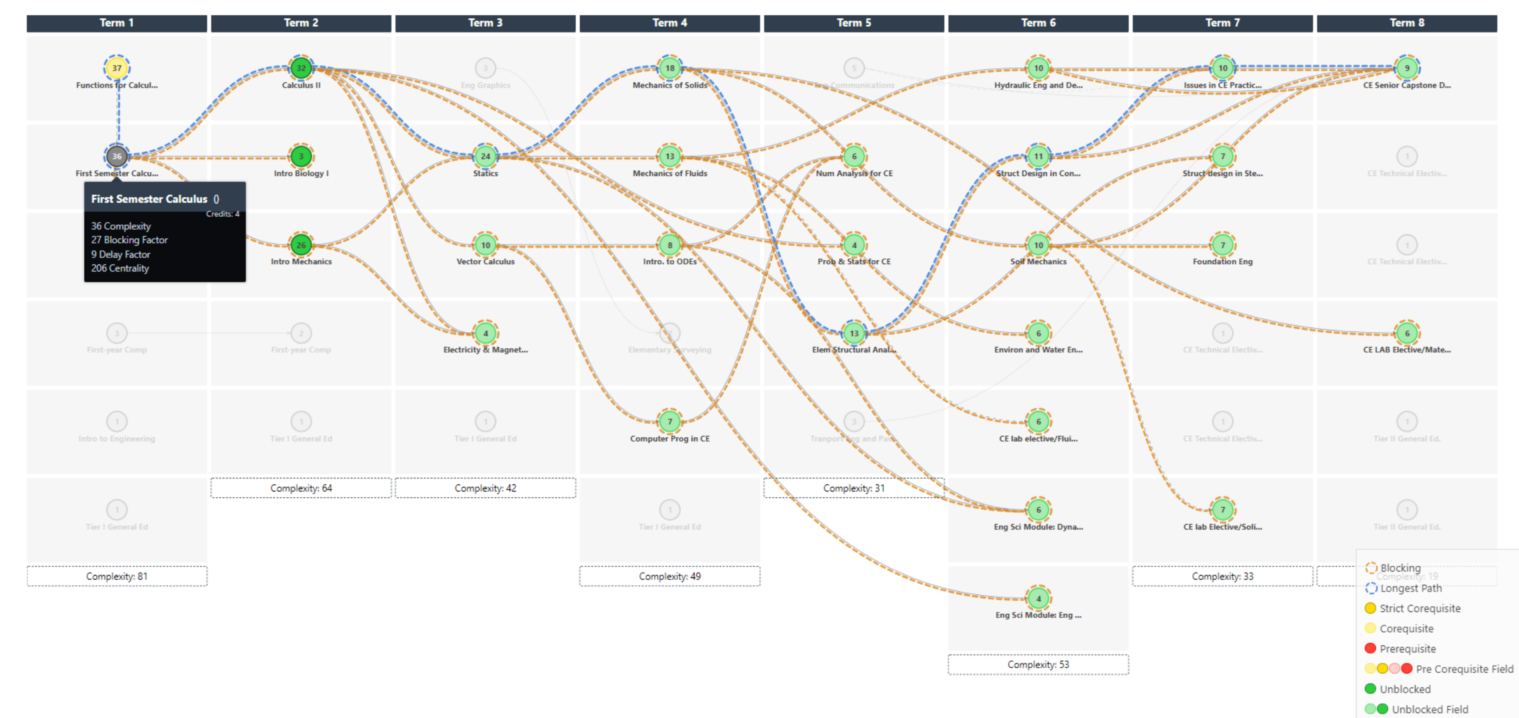
Appendix: Curricular Complexity

A theory of curricular complexity and a toolbox has been developed that relates curricular structure to time-to-degree[4] Specifically, as the structural complexity of a curriculum increases, and other factors are held constant, the time-to-degree will increase. Briefly, the structural complexity of a curriculum is given by the sum of the course complexities in the curriculum, and the complexity of a course is determined by its delay and blocking factors. In Figure 4 (b), an example is provided, where the Calculus I course in the first term is highlighted. This shows that there are 27 other courses in this curriculum that cannot be attempted unless the Calculus I course is first successfully completed; this constitutes the blocking factor of Calculus I in this curriculum. In addition, Calculus I is on a prerequisite pathway that includes nine other courses in the curriculum that must be passed in successive order; this constitutes the delay factor of Calculus I in this curriculum. The overall structural complexity of the curriculum in Figure 4 is 372, the highest of any civil engineering program in our study. The structural complexity of a curriculum is dictated by the courses in the curriculum and the prerequisite relationships between them.

An example curriculum is shown in Figure 4 (a).



(a)



(b)

Figure 4: A civil engineering curriculum with high structural complexity. **(a)** An eight-term degree plan for this curriculum, showing the courses and their prerequisites. **(b)** The same curriculum, with Calculus I highlighted in gray in the first term. There are 27 courses blocked by Calculus I (green courses), and the longest path in this curriculum (blue-dashed line) contains nine courses.