Efficient Curricula: The Complexity of Degree Plans and Their Relation to Degree Completion

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Introduction

Institutions of higher education are under mounting pressure to improve their retention and graduation rates. This is driven by numerous factors, including the desire to improve institutional characteristics for rating purposes and the increasing trend of states tying institutional funding to student outcomes, as well as the fact that a bachelor's degree has become an increasingly necessary prerequisite for success in the workplace—creating a moral imperative for colleges and universities to graduate the students they admit. Given these pressures, universities are collecting unprecedented amounts of information related to student performance and progress and applying ever more sophisticated analytical techniques in efforts to determine the most important factors that contribute to attrition and persistence.

The first studies in this country that were closely related to what we today call student retention were introduced in the 1930s as a result of the growing diversity of college opportunities available, including the emergence of selective institutions and the advent of the junior college. This was a time when John McNeely coined the term "student mortality" in his in-depth 1938 bulletin that collocated issues of timing and cause of student attrition (Berger and Lyon 2005). The nation then turned to matters of world war, both hot and cold, and it was roughly thirty years before Astin and others picked up the subject matter. Tinto's (1975) integration model led to the modern era of student persistence research; he cast the problem as "a longitudinal process of interactions between the individual and the academic social systems of the college during which a person's experiences in those systems . . . continually modify his goal and institutional commitments in the ways which lead to persistence and/or varying forms of dropout" (Tinto 1975, 94). Kuh et al. (2010) looked more closely at the institutional conditions—such as the policies, programs, practices, and cultural properties—that lead to student success. They found that the most important factor is *student engagement*, noting that it sits at the intersection of student behaviors and the aforementioned institutional conditions. Furthermore, unlike most of the other factors that determine student success (e.g., previous preparation, socioeconomic status, etc.), student engagement is a factor that can be influenced by the institution. In efforts to improve student success, many institutions took these lessons to heart and worked to increase the amount and quality of the student support services they provide (Kuh et al. 2006; Tinto 1987). For instance, many schools began to more rigorously and intentionally track the academic progress of their students, the extent to which they participate in educationally purposeful activities, the level of satisfaction with their campus experiences, and the added value (in terms of knowledge and skills acquired) of the entire undergraduate experience (Moore and Shulock 2009). Some institutions reported significant increases in student success as a result of their efforts, but with others the benefits were much more limited. An important trend, however, is that this work is now more commonly being driven by high-quality inquiries and analyses, often through studies with multi-institutional scope, in efforts to more accurately determine the "conditions that matter" for student success in college (Kuh et al. 2010).

The most fundamental measure of student success is degree attainment, and it is not uncommon to find heartwarming accounts of students who earn a degree in spite of the fact that multiple indicators gave them little chance of success—they succeed in spite of the odds. For these students, indeed for any student, the simple cold facts are these: if they are able to successfully navigate all of the requirements associated with a degree program, they earn the degree, end of story. In fact, at a very basic level it makes sense to think of all of the success-driven interventions mentioned above in terms of their ability to facilitate the movement of students through the individual requirements associated with degree programs. Indeed, in the end, the efficiency with which a student may progress through these requirements is what matters most. Certainly, creating institutional conditions "that matter" will facilitate student progression, but there may also exist structural conditions within the curriculum itself that limit progress independent of any success initiatives.

Degree attainment is generally tightly prescribed, requiring a student to accomplish a very specific set of goals laid out as a curriculum. This paper addresses student progress at this most basic level by investigating the structural properties of individual curricula to arrive at a measure of curricular efficiency. We contend that the role curricular efficiency plays in student academic success is more

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important than many realize and should be taken into account by those responsible for designing university curricula as well as support services. The remainder of this paper describes the efforts underway at the University of New Mexico (UNM) in this regard. We began studying curricular efficiency at UNM two years ago. Initially, we used Sankey diagrams to better understand how students flowed through the curricula at UNM during the previous seven years. This allowed us to counter numerous myths related to student progress at UNM and led to our study of the curricular efficiency of particular degree plans, along with the generation of curriculum graphs for these programs. We created graph-theoretic metrics for these degree plans and then compared them to those at numerous other four-year institutions. After accounting for student preparation, along with the graduation rates at these institutions, we found that the efficiency of a curriculum plays a significant role in determining the success rate of students at these institutions.

Visualizing Student Flows

Rather than studying the individual path a particular student takes toward graduation, which may not reveal the larger structural impediments related to the institution, we were interested in studying how particular populations of students flowed through the university system. Thus, we created visualizations of student cohort flows, overlaid on the structure of UNM, with the goal of uncovering deeper insights about the institutional factors that influence student success, or lack thereof. The visualizations resulting from this study, known as Sankey diagrams, are described below. We have found them helpful because they demonstrate how students flow through the UNM system in an intuitive and useful way. These flows make apparent the relative volume of students flowing through a program, where they come from, and where they go. An example, Figure 1a illustrates how a typical entering freshman class moves through the various colleges at UNM.

The incoming first-time, full-time class shown in Figure 1a consisted of 2,909 students, 2,742 of whom were initially placed in University College, 28 who were initially placed in the College of Arts & Sciences, and 139 who were admitted into the School of Engineering's Pre-major program. By the end of the eleventh semester, 1,196 (41%) of the original cohort had stopped out, 1,117 (39%) had graduated, and 596 (20%) remained enrolled at UNM.

Figure 1b focuses on a particular sub-flow of students corresponding to those who graduated within four years (i.e., the students that reached node GRAD8 in the diagram). This sub-flow clearly demonstrates the path that most of these students followed involved spending their first four semesters in University College and that the vast majority of students who graduated in four years did so in the College of Arts & Sciences.

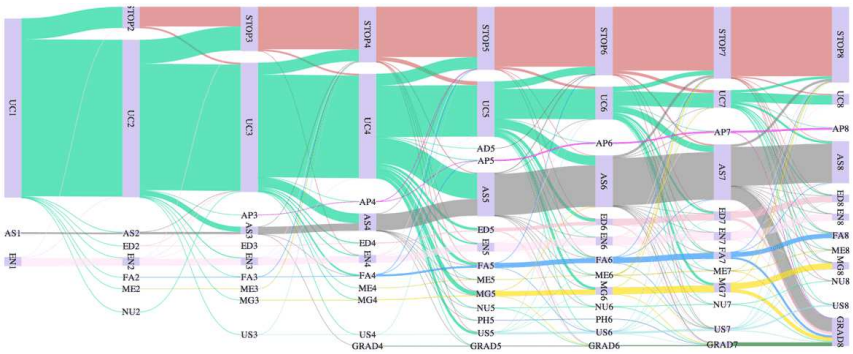

Figure 1a (full-size image)

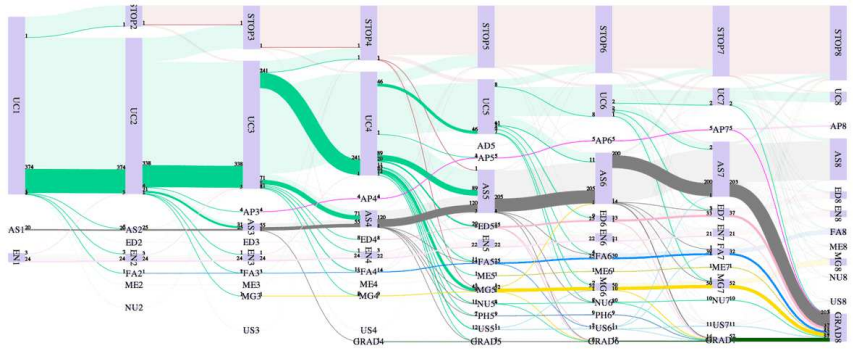

Figure 1b (full-size image)

Figure 1. *Sankey diagrams visualizing the flow of students from the 2007 first-time, full-time freshman cohort through the UNM system. UCx = University College in the x-th semester of enrollment, AP = School of Architecture & Planning, AS = College of Arts & Sciences, ED = College of Education, EN = School of Engineering, FA = College of Fine Arts, ME = Medical Education, MG = Anderson School of Management, NU = College of Nursing, STOP = student has stopped out, GRAD = student has graduated.*

Figure 1a: *The entire 2007 first-time, full-time freshman cohort.* ***Figure 1b:*** *The subset of students from the cohort that*

graduated by the eighth semester of attendance

We have created similar Sankey diagrams that track student cohort flows through the degree programs offered within our colleges and according to various factors—such as ethnicity, gender, ACT/SAT score, and so on. These also revealed many structural features that have an impact on how students move through UNM. At an even finer grain, we were interested in studying the impediments associated with students moving through individual programs. This led to the creation of the curricular graphs described in the next section, along with the study of curricular efficiency.

Curricular Efficiency

From a qualitative point of view, it is generally understood that within a given institution, some curricula are more difficult to complete than others. It is also the case that the most difficult majors are often the same at different institutions. Yet, some schools are far more efficient than others at graduating students in these majors, even when accounting for differences in student preparation. Thus, we were interested in answering these questions: Can the intrinsic difficulty of a program be quantified, and, if so, can it be used to identify any inefficiencies that may exist in the curriculum itself? Following is an overview of our attempts to answer each of these questions in the affirmative.

The set of requirements associated with the curriculum in a particular degree program, along with the relationships between the individual requirements (e.g., course pre/co-requisites), can be represented as a directed acyclic graph. Figure 2 includes example graphs for electrical engineering programs at two different universities.

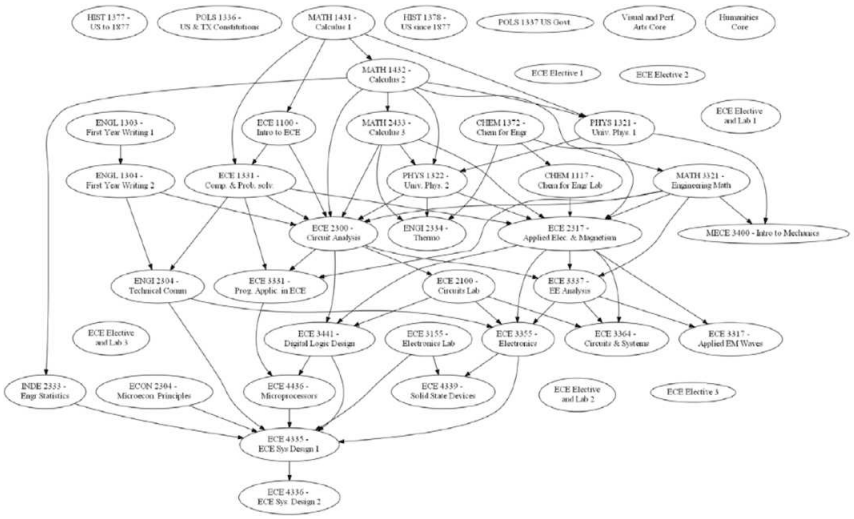

Figure 2a (full-size image)

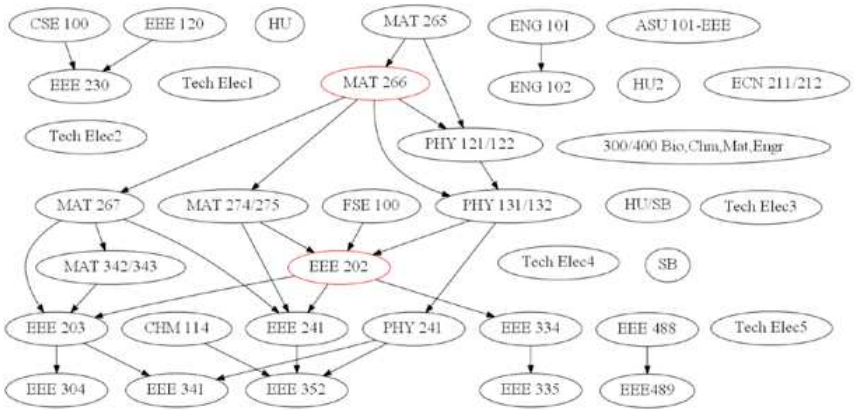

Figure 2b

Figure 2. *Electrical engineering curricula at two different four-year public institutions. The program shown in Figure b is more efficient than the one shown in Figure a.*

As the graphs show, even though these programs lead to the same degree, and are identically accredited, the degree requirements are vastly different. The curricular efficiency metrics we derived, described below, also show that the efficiency of the electrical engineering curricula in Figure 2b is much higher than that of Figure 2a. In other words, students enrolled in the former program will have fewer inherent difficulties completing degree requirements than those in the latter program. The actual graduation rates from these programs in fact validate this claim.

The curricular efficiency metric takes into account a number of factors. First, it accounts for the minimum

total number of credit hours required to obtain the degree associated with a curriculum. This is a fairly obvious factor that intuitively should inversely correlate with curricular efficiency but perhaps positively correlate with program quality (up to a threshold). The number of hours in a curriculum has a significant impact on the number of hours a student must take per semester to graduate in four years, and this trickles down to the number of hours a student must spend per week on school-related activities. Next, the efficiency metric incorporates the number of courses that have high node degree in the curriculum graph—these correspond to bottlenecks in the curriculum graph, where failure to pass a bottleneck course can lead to the inability to progress in a timely manner. More specifically, courses with high in-degree are difficult to reach, as every requirement must be satisfied before enrolling in the course, and courses with high out-degree are critical in the sense that success in these courses opens up the possibility for students to enroll in many other required courses in the curriculum. Another factor is related to the number of long paths in the graph. Long paths represent chains of classes that must be taken in order. Failing a class that is part of a long chain often requires a student to take summer school to get back on track or he or she will fall behind by a semester or year, depending on the availability of the class. The logic is that the more long paths, the more likely a student is to get off-track, get frustrated, and drop out of a program. The final factor, referred to as curriculum rigidity, is related to the number of prerequisites in the graph. As the total number of prerequisites increases, a curriculum becomes more rigid in the sense that students have less flexibility in the order that courses must be taken, and any failure to pass a course or take it on time is more likely to lead to a delay in graduation. Thus, a measure of the rigidity of a curriculum is given by the total number of edges in the curriculum graph, normalized by the total number of courses in the degree program.

Conclusions

Despite our improved understanding of student challenges and exponential increases in available data, complex personal challenges that integrate with more evident obstructions to persistence continue to cloud the student departure puzzle. Tinto emphasizes a focus on student persistence and not attrition, meaning there is more value in determining why students succeed than why they fail. The problem with this as a pure application is the shifting nature of psychosocial influences that can one moment enable a student to persist and, in another fleeting time frame, influence attrition. The common example would be immediate family support that motivates a student to pursue educational goals, yet inevitably may cause attrition sometime throughout a long and sometimes grueling four, five, six, or more years of higher education (Krumrei-Mancuso et al. 2012).

Considering the challenges of solving the complete puzzle, it is an efficient and useful investment for universities to continue to work on barriers to student persistence that are structural and independent of psychosocial aversions. In this case study, a deep investigation of student flow patterns combined with impactful graphical presentation highlighted a fundamental barrier of students progressing to degree-conferring colleges and led to a much more complex review of curriculum flow among programs. This in turn facilitated curriculum reform and the development of clear academic road maps available to students navigating their way through what is still a fog of requirements structured in an inefficient and sometimes inexplicable sequence. Ultimately, setting aside the discovery of confounding variables and visceral reactions that are contributing to persistence, attrition, or both has proven to be less critical than reexamining baseline student behavior. The result has yielded the implementation of technologically advanced tools to illuminate the student academic path, revision of curricular policy reducing and clarifying requirements, and a restructuring of the responsibility for student advising in schools and colleges.

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