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Exploring Curriculum Flexibility and Compliance through the Use of a Metric for Curricular Progression

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Abstract

The Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) contains academic records for students at ten partner institutions comprising over 10% of the United States' engineering students. The potential of MIDFIELD for curricular exploration is vast and has never been previously attempted. By using department graduation requirements for each ABET EAC-accredited MIDFIELD program and more than 400,000 engineering students, we construct a set of curricular checkpoints based on semester requirements being fully completed or not. While we discovered expected patterns within the construction of the metric, we also discovered indicators that engineering majors are vastly more flexible than previously thought. Almost 50% of students who graduated with degrees in engineering do not complete every course required by their major in their first, four semesters in the traditional manner. Furthermore, students not only enjoy flexibility in their early curricula but also enjoy through their later semesters where specialization courses dominate the curriculum. The aim of this research is to provide a new metric for describing the flexibility of engineering majors and further the discussion into how student progression through a major will require significant, future work.

Introduction and Background

The work of the MIDFIELD group has been widely disseminated and can be found on the MIDFIELD website.[1] Previously, the project has focused extensively on important engineering education issues such as: the persistence of students in engineering disciplines; the success of women in engineering using quantitative and qualitative approaches; a better understanding of the "pipeline" of engineering; and other important topics.[2-4] Throughout the history of MIDFIELD work, expanding into the realm of individual coursework has been sparse outside of using the database to examine certain "gatekeeper" courses,[5] such as first year calculus and chemistry. The project team needed to develop a method to look at wide groups of courses and find a way to describe patterns of student progression (or lack thereof) that could be applied across institutions. The reasons for that mindset are: first, discussion of sets of curricula seemed a more natural progression from studying large-scale persistence and graduation trends; second, it is complementary to previous MIDFIELD work that spoke to many long-standing myths within and without the community of student progression and/or "success"; third, it addresses the complete lack of measurements of system-wide curricular flexibility within our community; and fourth, with more than 38,000 different course numbers on file for institutions within the database, the construction of a thorough, individual course metric for all MIDFIELD schools is better left as a topic of a thesis or major research grant.

The need for more metrics of student success that address persistence[6] or curricular momentum[7] is clear. The engineering community of today has to grapple with an accreditation board who's standards have been criticized as not being readily assessable.[8] The papers consumed with calling for system-wide change that would address assessment issues have traditionally been products of expansive efforts by larger institutional bodies.[9] Although such papers could provide a suitable framework for the type of engineer institutions should produce, they have provided no definitive roadmap for the change they engender. The noted columns of the Engineer of 2020 are akin to the mandate of No Child Left Behind (NCLB): the report does not resound strongly across or unify the majority of engineering institutions in the United States or even internationally; the report provides no agreed-upon roadmap for discrete changes that are imperative; it comes with no system-building or capacity-changing funds; and finally, it is without apparent and feared consequence.

The purpose of such a metric may instill a sense of wariness in the engineering education community and within the post-secondary community at large. Part of the issue lies in the current state of data policy and integration at the post-secondary level. Collaborative data integration among post-secondary institutions has been sparse, with projects such as the National Survey of Student Engagement (NSSE) dwarfed by the results of K-12 systems such as the Integrated Postsecondary Education Data System (IPEDS).[10, 11] The complete lack of a federal unit records system has been of much consternation within multiple communities.[12-14]

The engineering education community itself has been consumed with the word *curriculum*; however, searches into journal articles and papers containing the word yield treatises on individual courses, historical underpinnings of the engineering curriculum's development, or case studies from schools whose revamped curriculum has engendered some sort of desirable change. We can examine the numerous calls for Project Based Learning (PBL) to be incorporated more closely into the engineering education curriculum[15-18] or ponder the calls for curriculum reform that focus on reforming one class or sets of classes in chemical or civil or mechanical engineering,[19, 20] or even the broader scope of calls to revamp curriculum as a whole.[21-24] We could even wade through a sea of calls to reform simply on the topic of capstone design, which paint the research scene like a deluge over a range of years[25, 26] The histories of engineering education themselves, whether reported by primary sources or modern sources, recount curriculum progressions usually from large-scale points of view.[27-30] The progression of post-Civil War engineering education through the "Great War" era and beyond often as recorded in histories tell interesting stories of complete curriculum overhauls as prompted by necessity or immediacy or in response to some common theme.

Methodology

The MIDFIELD database contains records for 572,205 first-time-in-college students matriculating in any major at participating institutions, of which 133,484 are first-time-in-college students matriculating in engineering 1988 or later as data are available.[3, 31] The population of this study consists of 51,388 first-time-in-college (FTIC) students who majored in engineering at eight institutions in the Multi-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) and graduated in any year for which data are available (many of those matriculating have not yet had enough time to graduate). The MIDFIELD schools are all public institutions and are mostly located in the southeastern United States, yet their size and diversity help make the results generalizable. These partner institutions have larger overall enrollment and engineering programs than average compared to the more than 300 colleges with engineering programs. The partners include six of the fifty largest U.S. engineering programs in terms of undergraduate enrollment, resulting in a population that includes more than 1/10 of all engineering graduates of U.S. engineering programs. MIDFIELD's female population comprises 21.5 percent of students, which aligns with national averages of 20 percent from 1999-2003[32] and 22 percent in 2005.[33]

The "curricular sets" constructed in this paper were constructed using the individual student data available in the database. Student electronic transcripts were compared to the required engineering curricula by major, semester and matriculation catalog year for every institution. If a student, at some point in the academic career, completed the required curriculum for a semester, then credit was given for completing that semester's required curriculum, thus a "Y" for a given semester's work means that a student had completed all of the required courses for graduation at any time during the student's career. In order to visually arrange the student curricular completion "pathway," the semesters are always ordered sequentially, so "YYYN" means a student successfully completed all of the courses in the first, three semesters of his/her major, and did not complete all of the courses in the last semester of his/her major.

It is important to carefully describe exactly what such a methodology includes and what it leaves behind. First, the "semester" in this method is comprised of the recommended sets of courses that are outlined by a student's major, and when they are taken does not matter. In this study, a student could take all of the "first semester" courses ten years after matriculating to a university, and the student would have a "Y" in the database to mark he/she completed the first semester's coursework. Second, the database is limited to all of the data provided by the institutions. Summer courses taken at universities other than a student's home institution and AP course credits do not appear on their records. Third, exceptions to the rules made internally are not part of the MIDFIELD database. An example of an "exception" would be students whose departments regularly allow them to waive a perquisite course upon completion of more advanced one. Such exceptions are largely ignored by the engineering education community.

This "binary tree" methodology lends itself to be a novel metric to the field of engineering education, and one previously unexplored in the field of student assessment. Other advantages of a curricular set metric include: the mathematical principles underlying such a method are accessible, making more advanced, quantitative analysis possible[34]; and there are multiple ways of visualizing such data that allow for exploration of significant patterns and presentation to a general audience.[35]

Findings

We completed preliminary analysis of our curricular completion schema by unfolding the sequence of semesters completed to four and seven levels represented by binary decision trees to track curricular patterns. The first set of figures demonstrates the curricular completion maps for the first, four semesters of students from eight MIDFIELD schools who graduated with degrees in engineering (Figure 1) and separated by gender into female (Figure 2) and male (Figure 3) groups. We further relegated ourselves to the domain of students who had graduated who were not transfer students and started in the fall semester.

From this proof-of-concept analysis, it is readily apparent that nearly a majority of students on (48.66%) followed an expected normative pathway to graduation of "YYYY." The converse, of course, is that the majority of students who graduated have at least one or more semesters for which they did not follow the standard path. Also, the second largest population is the group of students who only have a completed set of first semester's curriculum but not for the second, third, or fourth. Two more subtle results of note are apparent: having a "yes" in the second semester results in a "no" in the third semester being uncommon or undesirable; and analogously, students starting with an incomplete set of first semester's curriculum who proceed to have incomplete second and third semesters outnumber those with the same arrangement but complete the third semester's curriculum.

There are numerous differences between men and women. For instance, the biggest difference between the genders comes at the endpoint of YYYY, or students who completed all of the required courses in the first, four semesters. While the difference is small (~3%,) it is noticeable. At the opposite end of the spectrum, men on average had a 5.09% chance of having a NNNN compared to women having a 3.91%. While the difference here is a little more than 1% relative to the totals of both populations, the difference between the two factors themselves is more than 25%. The third most noticeable difference is in the population of students marks YNNN, or students having completed the full set of first semester's curriculum, but not the last three. Men had 11.6% for YNNN and women had a 10.2%. Once again, the difference relative to each gender's total population is small here, but the difference between those factors being about 10% is noteworthy.

Although a full analysis is beyond the scope of a conference paper, we have included for purposes of community discussion and for presentation the results from a seven semester analysis in Figure 4 and Figure 5. Of significant note are the patterns of students not having a "Y" well into their seventh semester.

Discussion

The divide between the students who complete all of their first, four semesters "by the book," versus the majority who do not would be easier if the majority of students who follow a non-standard pathway had a history in the literature, but they do not. One major result of this work is that it may be commonplace for students to take courses outside of their home institution. While a “N” in the first semester may indicate AP credit, a “N” in the fifth semester must mean that a specialization course was taken at another institution or waived altogether. There is no current model for such “extra-university” coursework, and this work serves as a starting point for such a study.

The notion of curricular momentum in engineering education[7] as observed by Adelman could be further explained by our work. It seems that students who graduate who enjoy flexibility in some sets of courses may be more attracted to continue enjoying such flexibility. The case as proposed by Adelman that engineering students tend to transfer to “hard” disciplines may serve as a model for what happens when engineering students decide to take specialization courses at other institutions, or take harder courses and have requisites waived. Furthermore, contrary to our previous work in MIDFIELD, the preponderance of options for the successful student, (and indeed the majority of students,) is a first order measure of the general flexibility of the engineering major.

There is certainly evidence that courses in the early curriculum can serve as gateway courses of those the calculus sequence is the most studied.[36, 37] This work extends that earlier work on the gateway characteristics of individual courses by exploring the synergistic gateway characteristics of an entire semester of the curriculum. The finding that curricular compliance in the second semester leads to curricular compliance in the third semester has implications for the identification of “gateway” courses on the engineering path.[5, 38] First, the notion that AP credit or first semester courses are the most skipped simply does not hold in light of our research. While the students who only have an incomplete first semester’s curriculum is significant (6.45% of the total), that percentage is within 2% of students who are NNNN or NYYN and within 3% of students who are NNNY, meaning that students who come in and immediately skip just first semester’s courses do not comprise the entire spectrum of students whose curricular path begins with an N.

While much of the literature has focused on the third semester—the semester in which the first disciplinary engineering courses are taken—as the “gateway” semester, our findings suggest that completing the second semester of the curriculum successfully is a critical stepping stone to completing the third semester of the curriculum successfully. This finding is even more critical if it should be shown that completing the specified curriculum successfully results in a quicker path to graduation—this is the subject of ongoing work. Certainly, as we have shown above, following the specific curriculum is certainly the most popular path to graduation, which suggests that the pathway is either one resulting in greater success or at least greater ease.

Looking at Figure 4 and Figure 5, an interesting result is distribution of students beyond the fourth semester who are not following the normative pathway. For instance, under the “NNNN” bracket, we see that the majority of students who graduated (of both sexes) are not NNNNYYY, but NNNNNNN, indicating that the likelihood of a student who has enjoyed great course flexibility in his earlier curricular set is most likely to continue upon that same pathway. The reason why that result is important is that technical or specialization courses in a major are not known to be "portable," or easily taken outside of one's home institution. In fact, there is no study on record that has accurately described the phenomenon of students undertaking significant amounts of work outside of their home institution in their later years.

Conclusions and Future Work

The current literature on curricular flexibility within engineering education would benefit from a new metric to examine curricular sets in a broad fashion across multiple institutions. Our results presented here are a proof-of-concept that indicates future analysis may lead to significant results. Of primary importance in future work is analyzing the small yet significant number of students who do not complete their complete curriculum requirements in their third and fourth years of their engineering major. We are currently using our newly-acquired data to construct decision tree models, as dichotomous variables work well for such methods of analysis. Also, this methodology includes only FTIC students who completed degrees in engineering. It does not set any temporal limit on the number of years until degree completion, although it could take that into account in future work.

The need for further work on curricular progression metrics is evidenced by the dearth of robust techniques within engineering education to study sets of students throughout their collegiate career. In its current state, the community has not addressed a semester completion metric, and while in its infancy, it appears to show promise as a metric that has potential for widespread application.

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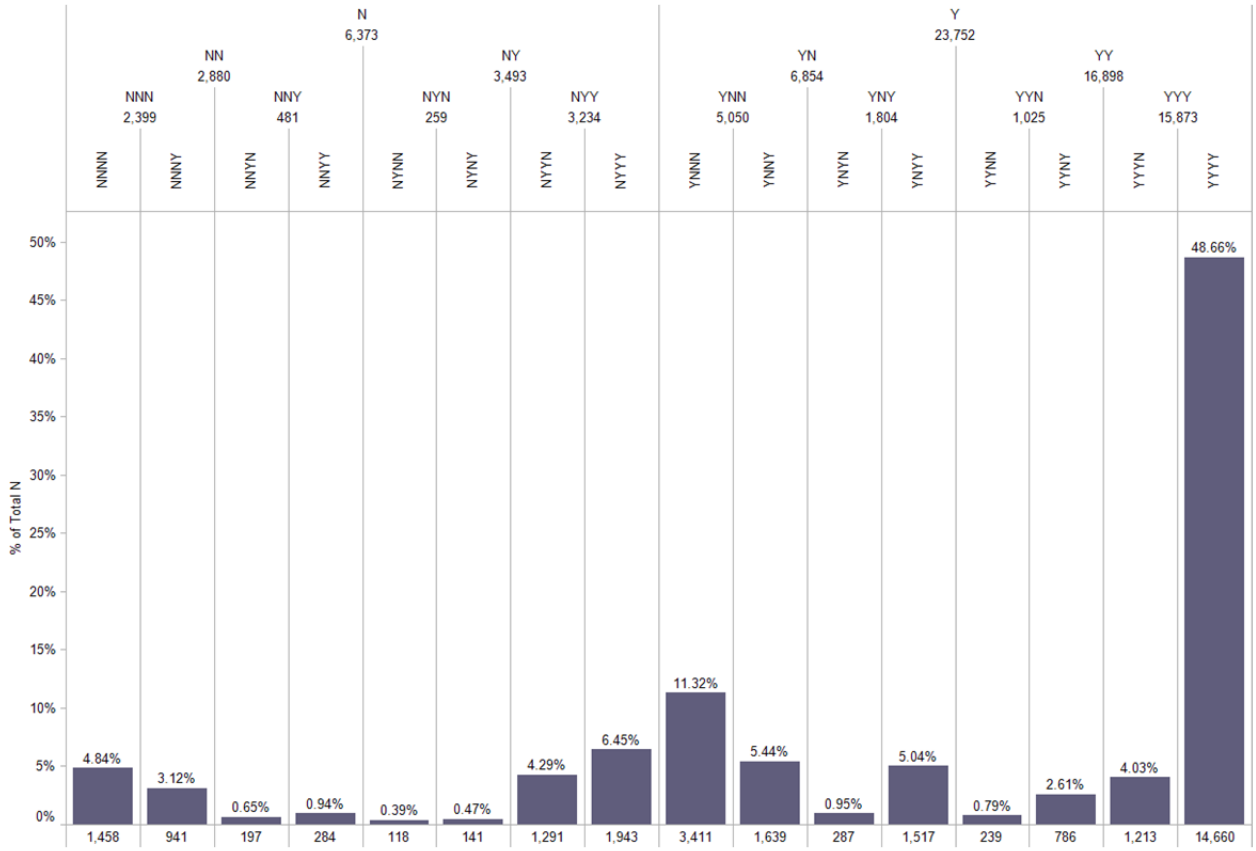

Figure 1. Chart showing curricular set completion pathways for the first, four semesters of female students in eight MIDFIELD schools. The first (Y/N), second (NN, NY, etc), and third (NNN, NNY, etc) levels have the relative number of students marked immediately below them. Each level's numbers will sum to the same number as any other level. The numbers and percentages below the bars at the bottom refer to the distribution of students for their first, four semesters of coursework. Thus, a "NNNN" at the bottom represents all of the students who graduated who do not have every required course in their first, second, third, and fourth semester's curriculum on file defined by their major requirements.

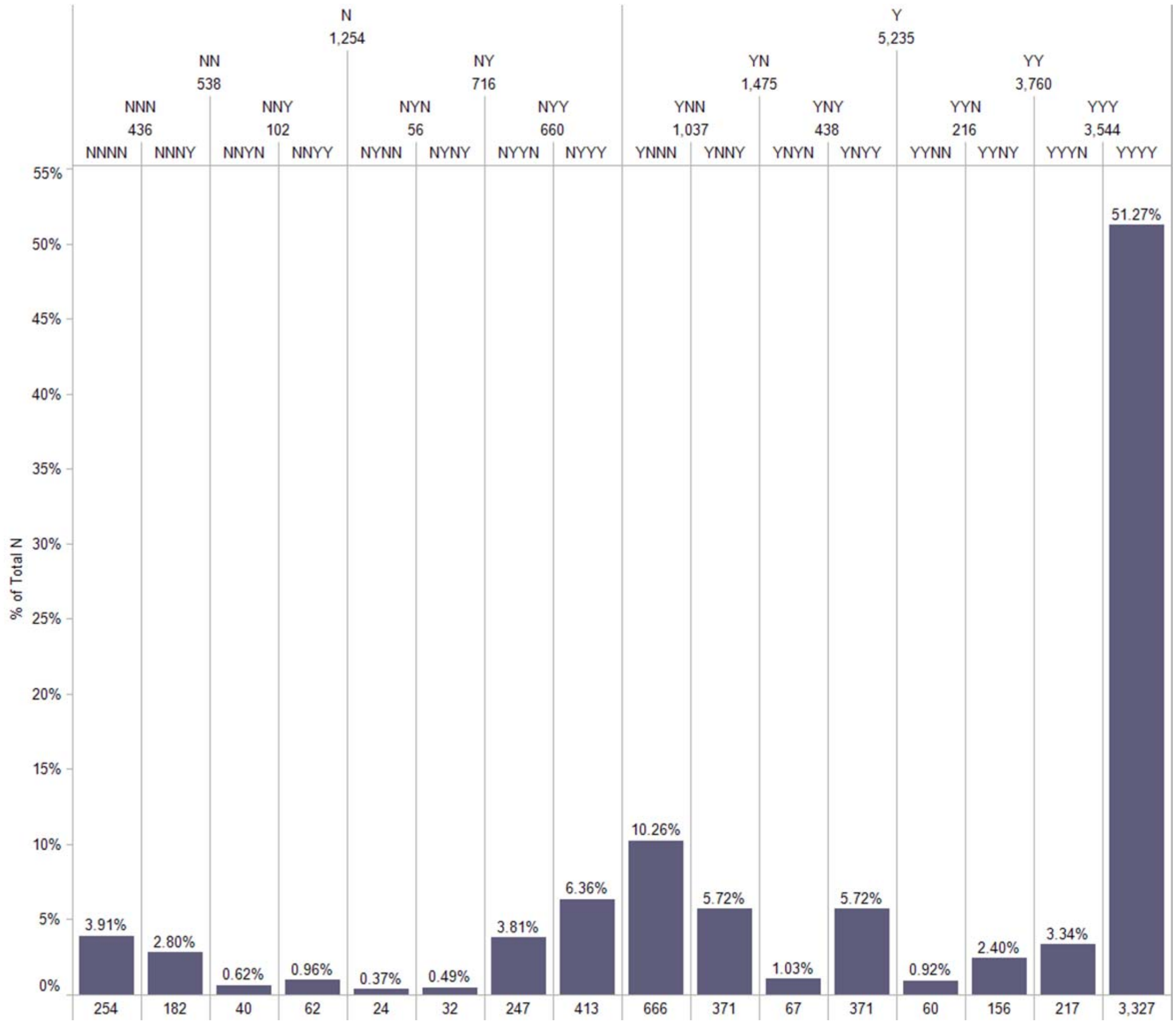

Figure 2. Chart showing curricular set completion pathways for the first, four semesters of female students in eight MIDFIELD schools for females only.

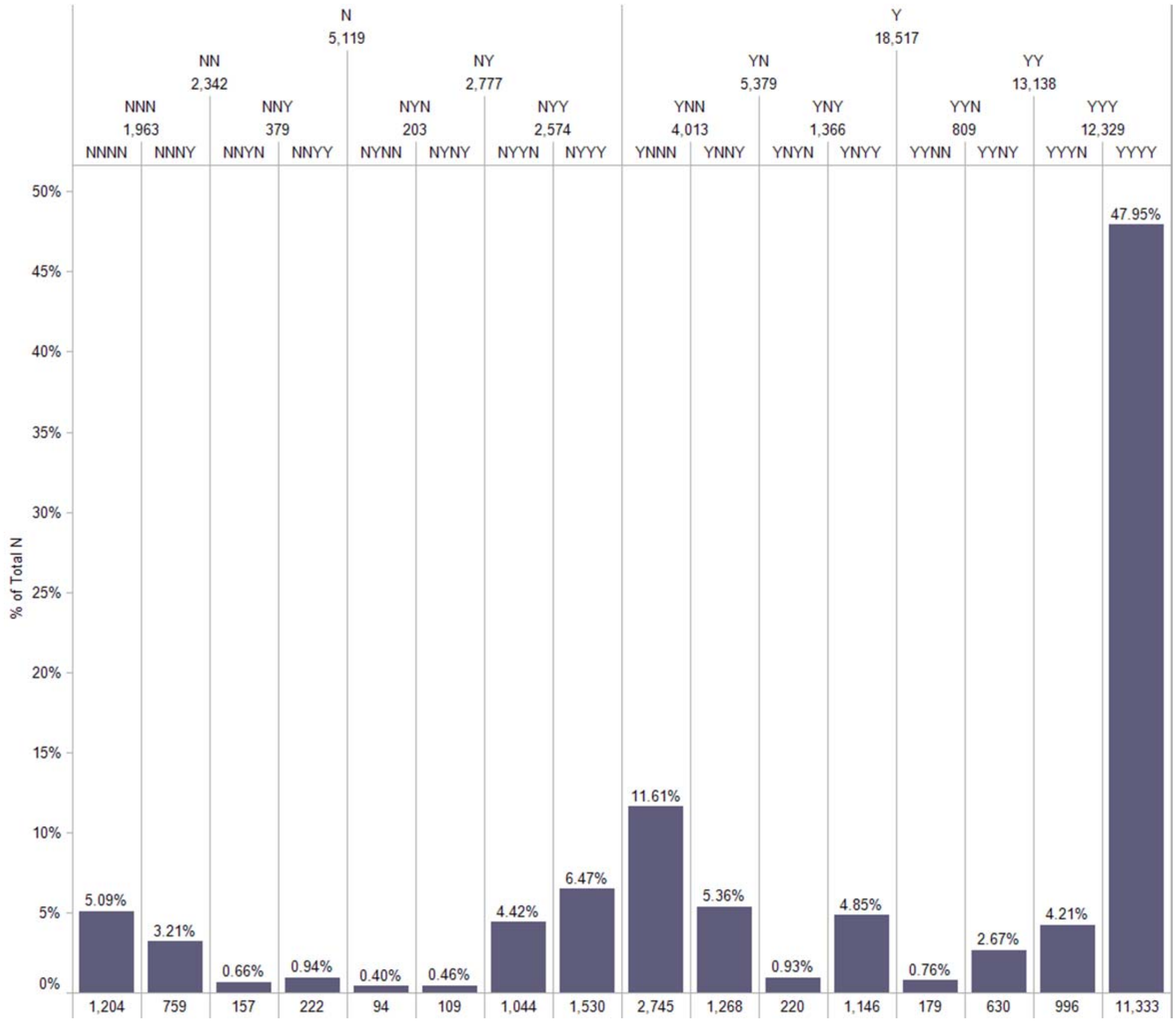

Figure 3. Chart showing curricular set completion pathways for the first, four semesters of male students in eight MIDFIELD schools for males only.

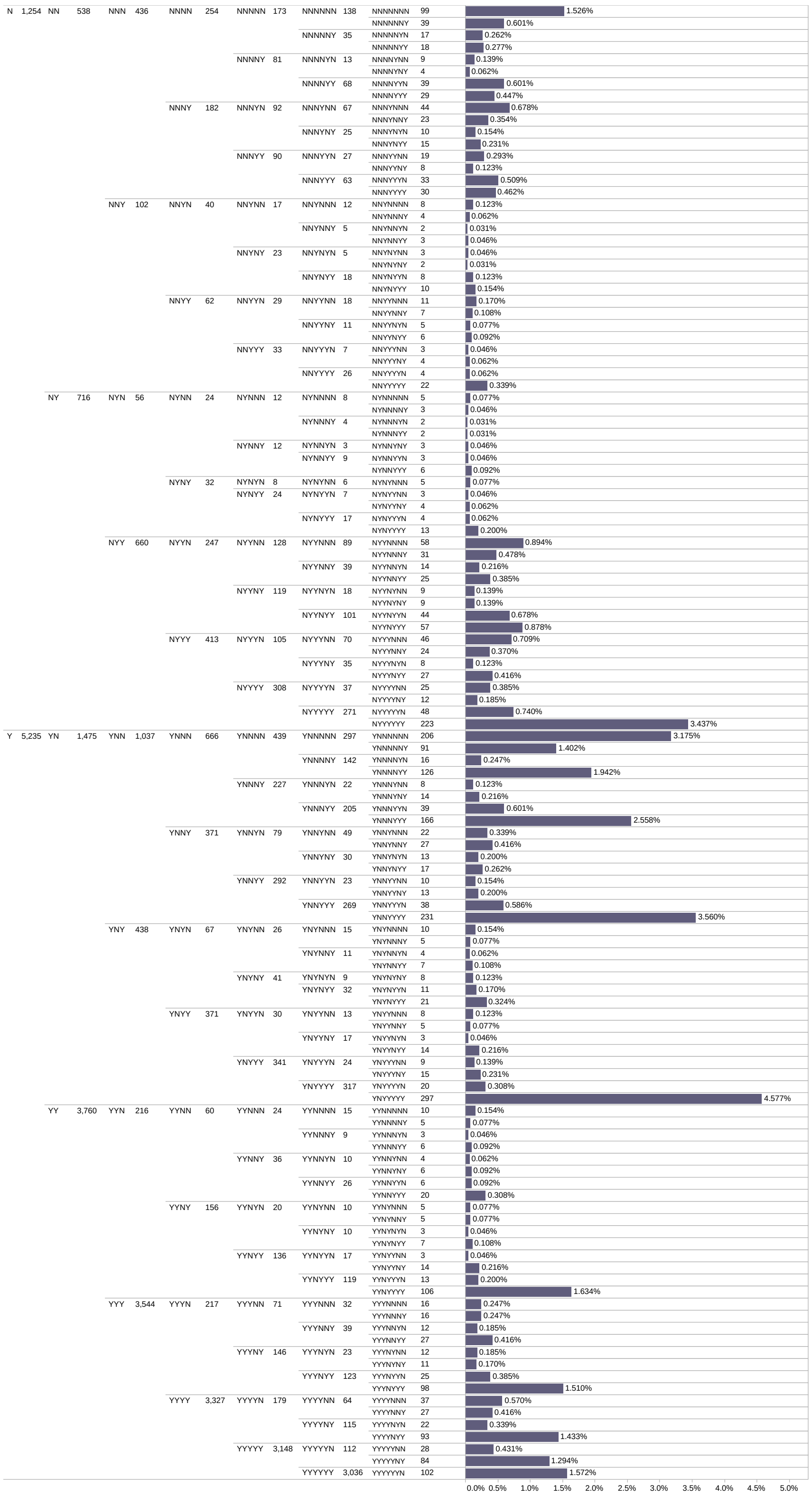

Figure 4. Curricular map expanded to seven levels for females. The largest population is hidden (YYYYYYY or 45.21%). Total student Ns for the seventh level are to the left of the bars.

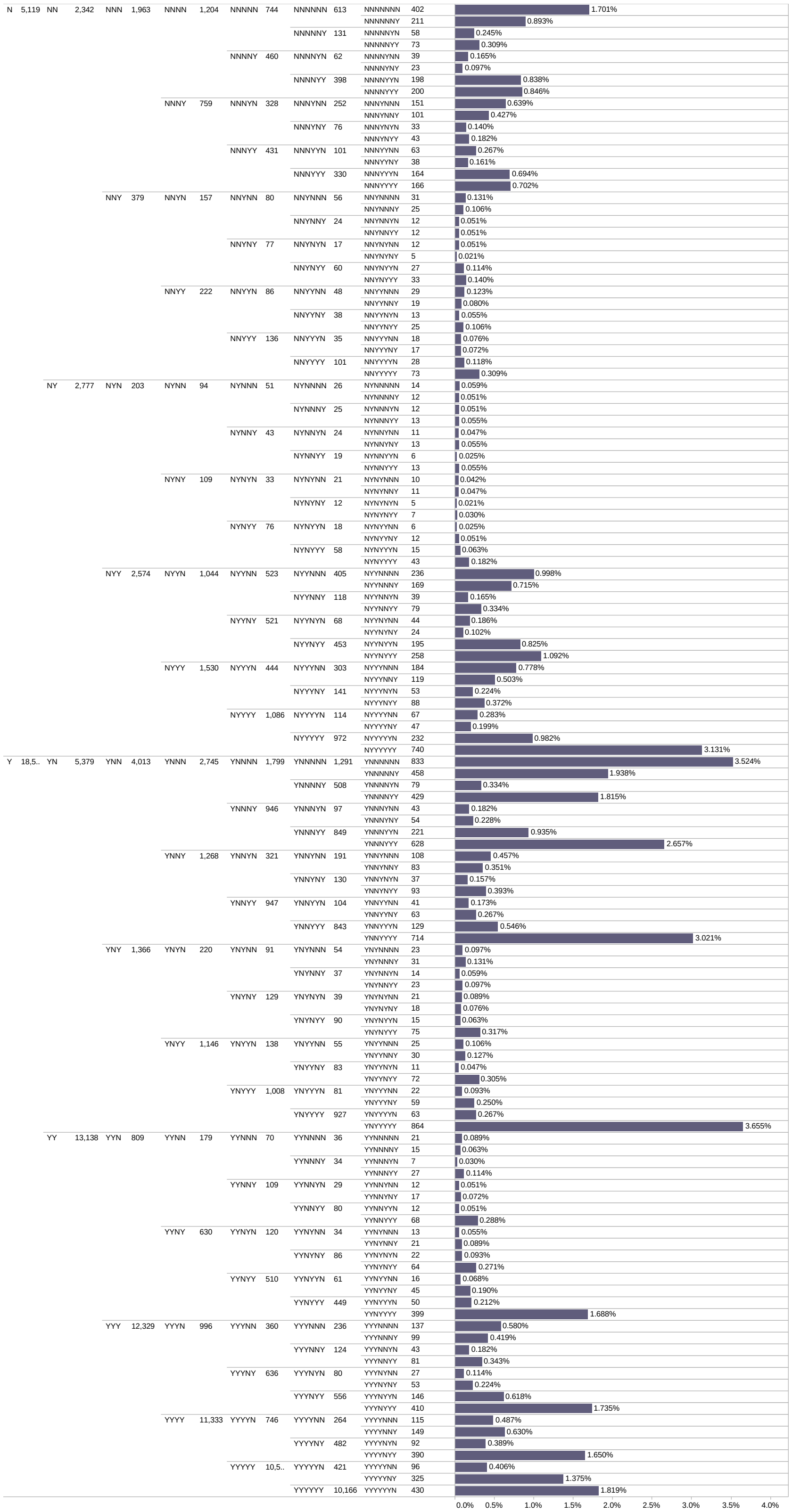

Figure 5. Curricular map expanded to seven semesters for males. The largest population is hidden (YYYYYYY or 41.19%). Total student Ns for the seventh level are to the left of the bars.