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The Impact of Doubling Department Course Offerings on Faculty Load and Student Success

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Abstract:
In the past 10 years engineering schools have seen increases in both student enrollments and student tuition. Further, numerous engineering departments have implemented evidence-based pedagogical practices that increase student success, engagement, and faculty and staff work load. Across the country engineering departments strive to strike the delicate balance between maintaining reasonable faculty/staff workloads while attempting to improve student success, measured through time to degree and student attrition metrics. The University of Colorado at Boulder Aerospace Engineering and Sciences Department has historically offered junior level courses once per year, all of which are prerequisites for a year-long senior projects course. For the past two academic years, the department has shifted to offering every junior course twice per year, theoretically allowing students that fail a course to graduate on time. This paper aims to study the impact of this change on both student success and department resources. It is found that offering courses twice per year did not have a large impact student time to graduation metrics, but did require more allocated faculty members.

Introduction
In the past decade enrollment in STEM degrees has steadily increased; at large public universities engineering departments may have enrollments ranging from 800 to 2000 undergraduates. During the same time frame, engineering departments have made a concerted effort to incorporate pedagogically strong engineering education methods into their curricula, such as open-ended laboratories and project based learning courses. Further, in the past 20 years tuition at public national universities has increased 212%, resulting in intense pressure on students to complete rigorous engineering degrees in minimal time.

All of these variables require considerable resources and therefore act in direct opposition to department budgets and hiring constraints. Large cohorts of students require either big classes or multiple sections of a class, driving the need for huge lecture halls or several faculty with expertise in the subject area. Scaling open-ended labs and project based learning courses to large classes is exceedingly difficult as these teaching techniques require significant faculty time, skill, and department resources. Providing a curriculum that allows students to quickly complete engineering degrees often requires multiple class offerings per year.

Initially the Ann and HJ Smead Aerospace Engineering and Sciences (AES) department offered each of the six required aerospace junior courses once a year: three were offered in the fall semester, and the remaining three were offered in the spring. Note that the junior classes require significant department resources as each course is 4 credit hours; 3 credit hours of lecture and 1 credit hour of lab for hands-on experimentation. To improve flexibility, the department changed the curriculum to offer all six required junior aerospace engineering classes in the fall AND in the spring semesters. In this new curriculum, students could fail a junior class in the fall and then re-take the course in the spring, potentially not delaying graduation at all. However, it is unclear if the higher spring course load would be manageable for students already struggling.

To further understand how curricula changes impact both faculty and students, this paper will examine the following research questions:

1) Was there a change in junior course DWF rates after the curriculum change?
2) Do students who struggle in the junior year recover to graduate with a degree in AES, and what does this recovery look like?
3) Will this curriculum change potentially decrease the undergraduate student time to degree metric?
4) How did doubling the junior course offerings impact the department's ability to cover undergraduate courses?

Literature review:

Changes to the cost of university, enrollment, and engineering pedagogy have had significant impacts on both students and faculty. STEM enrollment at U.S. universities increased 44% in 9 years from 427,503 full time students in 2009 to 616,200 in 2018 according to Roy et al.[1] Locally, enrollment in CU Boulder's aerospace engineering program has nearly doubled in the last five years from 570 enrolled students in 2015 to 1055 students in 2020.[2] Additionally, students are paying more to attend college. The average in-state tuition and fees for public universities have increased 212% in the past 20 years, putting pressure on students to finish engineering degrees quickly.[3] As the number of students and price of tuition has increased in engineering programs throughout the U.S., pedagogical practices have shifted to focus on hands on, open-ended learning in engineering in the past decades.[4] Further, college degrees remain important for upward economic mobility; Carnevale characterized post Great-Recession employment opportunities by education level and found that students who withdraw from university are known to have far fewer employment opportunities than those who obtain a bachelor's degree.[5] The increase in student enrollment, tuition cost, and faculty load combine to severely constrain both student and engineering department resources. It is critical to understand how engineering curricula design impacts both students and faculty in order to optimize student success and faculty load.

Universities use multiple metrics to quantify student success. The time it takes to earn a degree is coined time to degree and is a top indicator of student success.[6] Though most engineering undergraduate programs are designed for four years, the average time to degree is significantly longer. Lowering the time to degree is an effect of academic momentum that is likely to increase graduation rates and lessen financial burden on students according to Attewell and Monaghan.[7] DWF rates (the percent of students who received a D, F, or withdrew from the course) are used to quantify student performance within a specific course. These metrics can be related to the number of students that leave engineering or struggle throughout the curriculum. It is common for studies to use DWF rates to assess changes to individual courses such as Howard's investigation of how changes to an engineering statics course led to lower DWF rates.[8]

Significant work has been done to determine predictors of student success in engineering curricula. Ackerman found that high school GPA and standardized exam scores are accurate predictors for post-secondary academic success in engineering programs.[9] Additional factors such as high school preparation, exposure to STEM, and student confidence in math also contribute to a student's early academic success in engineering.[10] Poor grades in key early courses such as physics and calculus are a clear factor that pushes students to leave engineering as observed by Suresh.[11] Student performance in critical course sequences acts as a predictor for long-term success and retention. In Georgia Tech's mechanical engineering program, students who struggle in freshman physics were more likely to struggle throughout the course sequence, and students who failed freshman physics were likely to leave the institution in general. [12]

A number of studies have been done to analyze the impact of curriculum design on student success. Hieleman analyzed curriculum complexity using a systems engineering approach where fundamental course sequences are comprised of prerequisite chains that are often structurally complex.[13] The study characterizes complexity in engineering curricular patterns as the sum of the blocking factor (the number of courses relying on a prerequisite) and delay factor (the number of courses within a prerequisite chain) of all courses within a pattern. A correlation was found between structural complexity and the time to graduation using this systems engineering approach. By rearranging the pattern or creatively designing alternative paths for students, structural complexity can be lessened and time to graduation can be decreased. Wigdahl investigated the relationship between curriculum rigidity/prerequisite chains and curriculum efficiency within the University of New Mexico's electrical engineering department.[14] The aforementioned studies focus on simplifying engineering curricula to shorten the time to graduation and increase student persistence, but they do not examine how performance in core classes affect student success.

This study examines the impact of a relatively simple change to the engineering curriculum in a single department on both students and faculty. Junior course offerings were doubled from being offered once an academic year to being offered twice an academic year, with the goal of increasing curriculum flexibility. In particular, the department strived to ensure students who failed a junior course did not have to wait a year to repeat it, and were potentially able to get back on track for an on-time graduation. However, increasing the number of junior course offerings increases the load on the department in terms of faculty teaching load, space constraints, lab equipment, and teaching support resources. This study performs a deep dive on the impact of doubling these courses on both student success and faculty load, with the end goal to optimize the use of department resources while maximizing student success.

Curriculum Background

Students in the AES department begin with standard courses such as calculus, physics, and computer science in their first year. Aerospace engineering coursework is first incorporated into the curriculum during the second year. Statics, thermo/aerodynamics, dynamics, and vehicle design courses are taken during this year, and each course is supplemented with one to two credit hours of lab outside of a three-credit hour lecture. Note the sophomore courses are currently only offered once a year. The curriculum intensifies junior year when students are expected to complete six aerospace engineering courses, each with a lab. The topics of the cumulative 24 credit hours of junior coursework/lab are structures, aerodynamics, thermodynamics/heat transfer, orbital mechanics/attitude determination and control, aircraft dynamics, and electronics and communication. Students who receive a C- or less in an aerospace course must repeat the course for a grade of C or above before taking follow on courses. All junior aerospace courses are prerequisites for the year-long senior projects course. This curriculum design allows students to have a strong technical foundation for senior projects while giving them time to complete technical elective courses during their senior year. Note that the year-long senior project course only enrolls new students in fall semesters.

Up until Fall of 2019, junior aerospace courses were only offered one semester per academic year. Starting in the Fall of 2019, junior aerospace courses were offered both semesters (one section per semester). All sophomore and junior courses are team-taught by two faculty members.

Data Set

The University of Colorado at Boulder Office of Data Analytics provided the authors with secure protected files with student grades for all junior courses, GPA at graduation, start date, graduation date, graduation major, last enrolled date, and last enrolled major. Data was collected for AY16/17 AY17/18, AY18/19, and AY19/20, for a total of 653 students.

Results

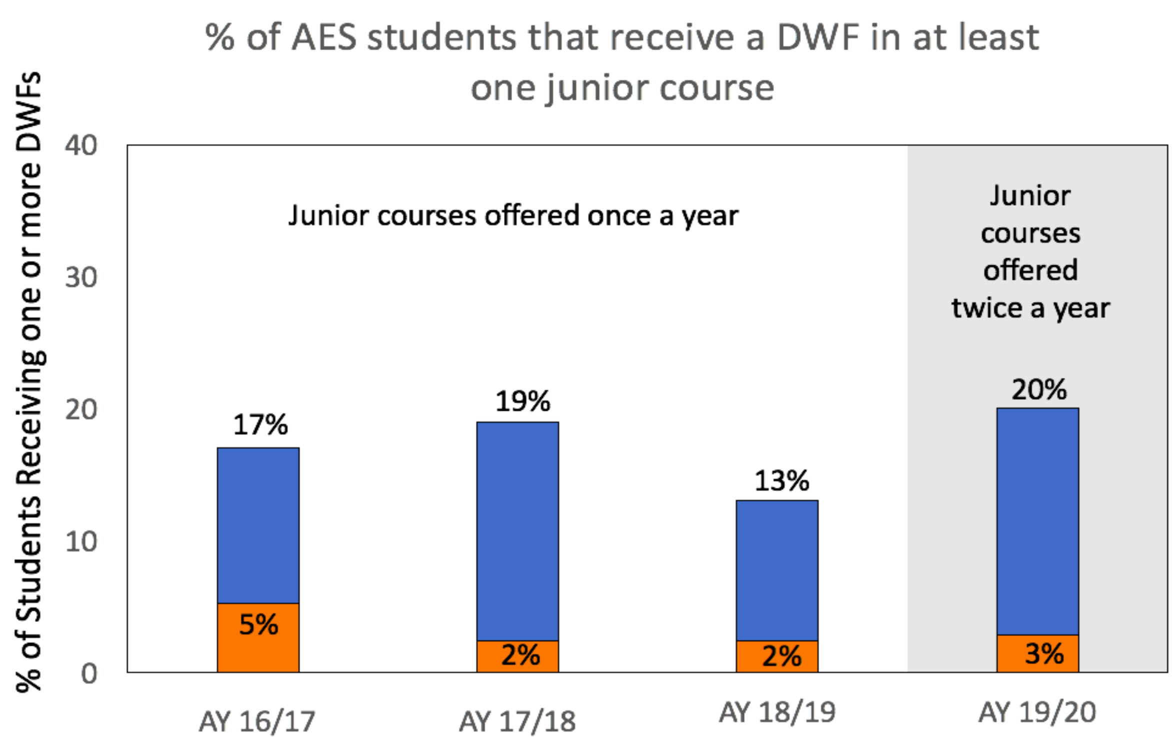

Figure 1: Percentage of aerospace students who received a C-, D, W, or F in one or more junior aerospace course. Blue indicates the DWF rate for that academic year. Orange indicates the attrition rate of aerospace students who received a DWF in a junior

aerospace course. For AY16/17, n = 131. For AY17/18, n = 141 students. For AY18/19, n = 193 students. For AY19/20, n = 188 students.

To attempt to answer RQI, if DWF rates changed when junior course offerings were increased to twice a year, the DWF rates for students in their junior aerospace courses were calculated for the 2016/2017, 2017/2018, 2018/2019, and 2019/2020 academic years. DWF rates were calculated by: (# of students who received a C-, W, D, or F grade in any of their junior classes)/(total # of students taking junior classes in a single academic year). Note that if a student failed multiple junior classes, this student would be counted as one struggling student. DWF rates varied from 13 to 19% when junior courses were offered once a year, and the DWF rate was 20% when junior classes were offered twice a year. Statistical comparisons cannot be made as there is only a single year of data for junior courses being offered twice an academic year. Junior year attrition rates were calculated as the percent of students who left the aerospace curriculum immediately after receiving a C-, D, W, or F in a junior aerospace course. Attrition rates varied from 2% to 5% for years that junior classes were offered once a year, and was 3% for the year junior classes were offered twice a year.
Note that the coronavirus pandemic hit in the spring semester of AY19/20, and grading policies were changed to allow for students to opt into P+/P/F option up to the last day of the semester. Students who elected into this P+/P/F grading scheme received a P+ for a grade of C- or better, a P for a grade of D, and a F for the grade of F. Due to this policy, students who would have gotten a C- and normally be required to repeat the course could have received a P+ and passed the course.

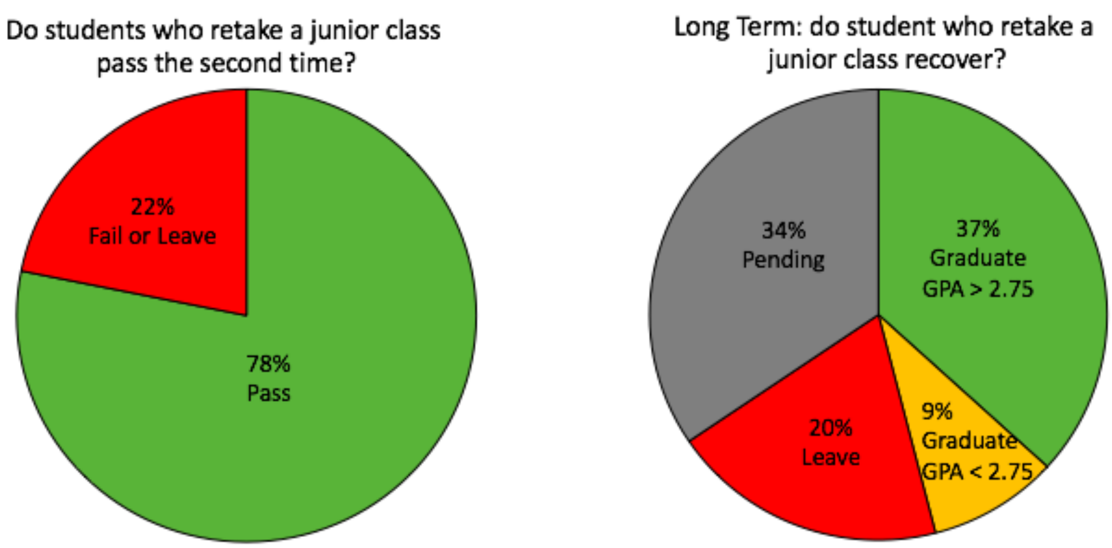

Figure 2: Student recovery in junior courses. N = 87.

To answer RQ2, do students who struggle in junior aerospace courses recover, we studied the grades students received when retaking junior courses. This cohort of students included aerospace students who received a C-, D, W, or F the first time they took a junior level class in the academic years of 2016/2017, 2017/2018, 2018/2019. Almost 80% of students who initially failed a junior course were able to repeat the course and earn a passing grade. To determine if students were able to fully recover to graduate with an aerospace degree, student status as of Fall 2020 was examined. Close to 40% of students who initially failed a junior course were able to graduate with a GPA higher than 2.75. Note that most aerospace companies have GPA cutoffs for hiring around 2.75 to 3.0. Close to 30% of students graduated with a GPA less than 2.75 or left the aerospace program all together. Finally, 34% of students had not graduated from the aerospace department as of Fall 2020, but were still enrolled in aerospace courses.

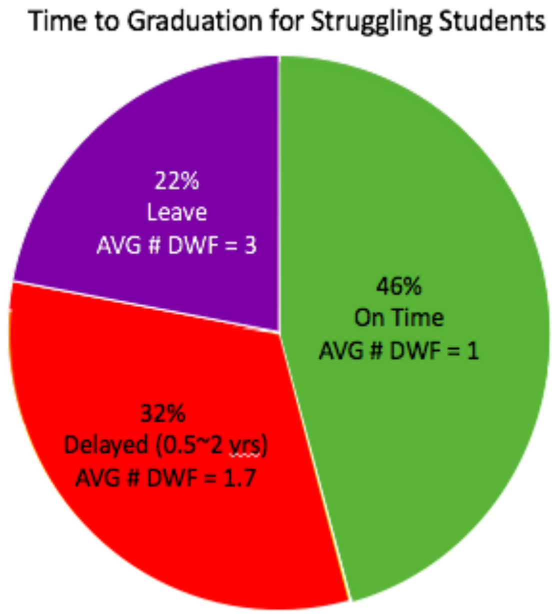

Figure 3: Time to degree for students who struggled in a junior course in AY2016/2017, AY 2017/2018, AY2018/2019. Total cohort = 417 students. Of the 417 students, N = 59 students struggled in their junior courses.

To determine if student time to degree rates would be improved with doubling the junior course offerings (RQ3), we first examined how failing a junior class impacted a student's time to degree when junior courses were only offered once a year. Figure 4 shows the time to degree for students who received a C-, D, W, or F in one or more of their junior courses in academic years where junior courses were only offered once a year. Time to degree was measured from the point a student failed a junior course to when the student graduated, where an on-time graduation would be 1.5 years after taking a fall junior course. Almost 50% of students who failed a junior course were able to recover and graduate on time. This was due to a department policy which allowed students to petition to repeat a single failed junior course their senior year while enrolling in the required year-long senior projects course. Recall that all six junior aerospace courses are prerequisites for the year-long senior projects course. Note that students who managed to recover and graduate on time on average had only failed one junior course. Roughly 30% of students who failed a junior course were delayed between 0.5 and two years, and on average had failed 1.7 junior courses. A bit over 20% of students left the program after failing a junior class, and on average had failed three junior courses.

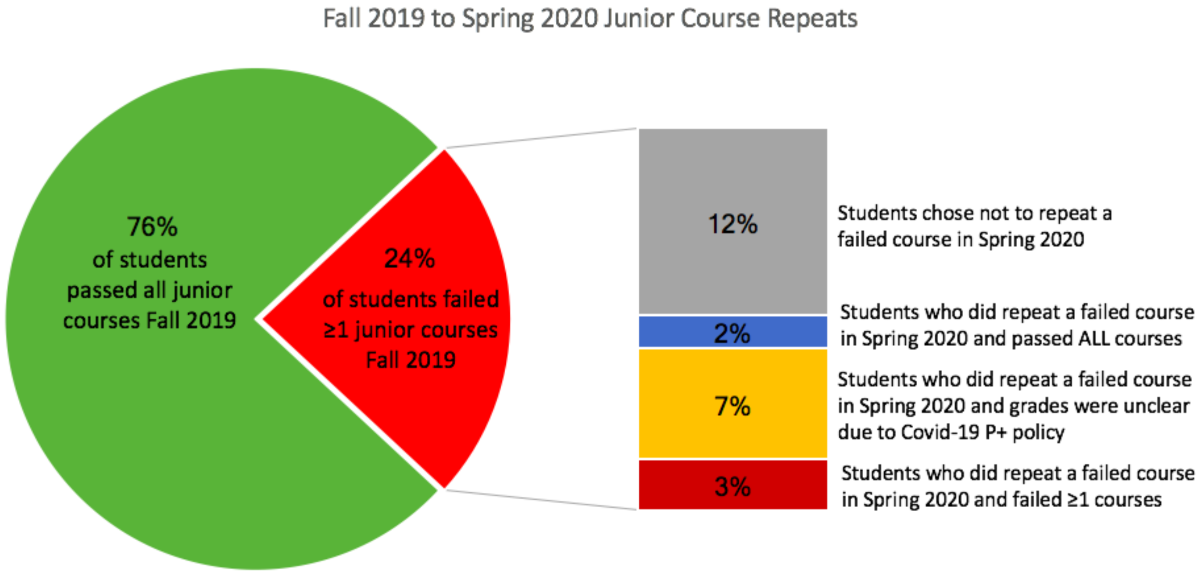

Figure 4: Breakdown of students who failed a junior course in the Fall of 2019 and had the option to repeat the course in Spring 2020

To understand if doubling the junior course offerings would improve student time to degree, we examined the choices and performance of students who failed a junior class in the fall semester and had the opportunity to repeat the course in the following spring semester. The first year that all junior courses were offered in both the fall and spring semesters was AY 2019/2020, with a cohort of 188 students. 24% of students failed one or more junior courses in the fall of 2019, and half of these students (n = 23) chose to repeat a failed junior class in the spring of 2020. Of these 23 students, four were successful in passing all their spring junior courses. Six students failed one or more of their spring junior courses, rendering the retaking of a junior class moot.

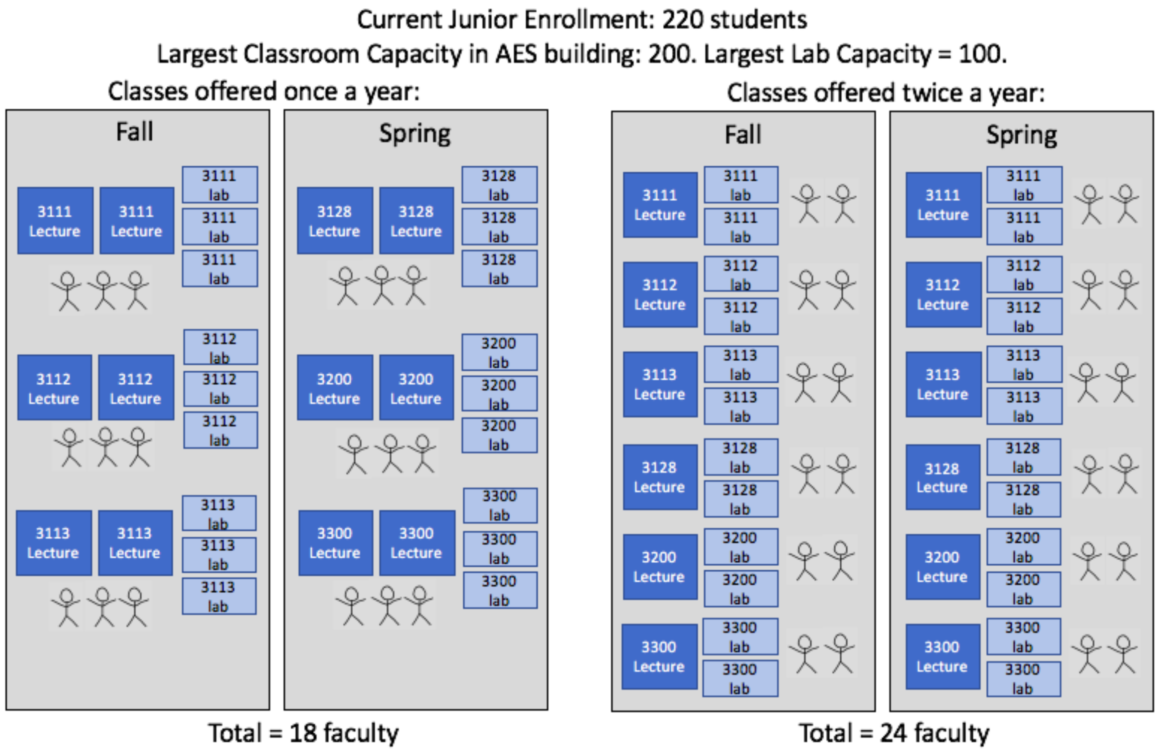

Figure 5: Breakdown of enrollment, building capacity, and number of teaching faculty needed for offering the junior courses once a year verse twice a year.

To answer RQ4, how doubling the junior courses impacts the ability of the department to cover courses, the constraints around enrollment, building room capacity, and number of faculty needed to teach the courses are illustrated in Figure 6. Recall that the aerospace department uses a team teaching approach to tackle its lab centered curriculum, where most core sophomore and junior courses are taught by two faculty members. To offer junior courses once a year at an enrollment of 220 (roughly the enrollment of 2020/2021), two lecture sections and three lab sections would be required, and this load would be split across three faculty members. If junior courses are offered twice a year, one lecture section and two lab sections would be required per semester. This load would typically be taught by two faculty members. Therefore, offering junior classes twice a year does require 6 more faculty. Teaching assistant allocations would be the same across both course offering configurations as these are based purely on student enrollment in a course.

Discussion:

Overall, our studies show that while roughly 1 in 5 of students fail a junior course, eighty percent of these students recover to pass the course after retaking it. As a relatively high percent of students will need to retake a junior course, the curriculum and policies surrounding junior course repetition certainly have an impact on student success. At first glance, the junior year curriculum seemed quite rigid as it only offered the six required courses once a year, and all six courses were pre-requisites for the year -long senior projects course. However, we found that almost 50% of students who failed a junior course were able to graduate on time. This was due to a policy which allowed students to repeat a single failed junior course their senior year concurrently with senior projects. These results highlight how powerful department policies can be in terms of providing curriculum flexibility. Note that the students who were not able to graduate on time had on average failed 1.7 courses. Failing more than one required course in the junior year would likely make an on-time graduation difficult in the majority of engineering curricula.

When the department moved to offer junior courses twice a year, the question arose of whether students who failed one of their three junior aerospace courses in the fall would be able to successfully repeat the course in the spring. Doing so would give them a spring course load of four junior aerospace courses (16 credit hours). Anecdotally, students often comment that the junior year is the most technically rigorous year of the curriculum. Note that while the senior year curriculum is time consuming with the senior projects course, it can be less rigorous depending on the technical electives a student selects. The first academic year junior courses were offered each semester, 50% of students who failed a course in the fall chose to repeat the course in the spring. The remainder of students chose to repeat the failed course in the fall of their senior year. Of the 23 students who did choose to repeat their failed junior course in the spring, 13 did so with a course load of four junior aerospace classes, and 3 passed all four classes with a C or above. The remainder of students either received a P+ or failed one of the four junior courses. Note that the Covid-19 pandemic occurred in this spring semester, and resulted in a rapid transition to online learning, significant stress on educators and students, and the P+/P/F grading policy, all which could skew some of our results. To get a more robust data set and map of the impact of this change on student success, it would be best to track student progress over multiple years of this curriculum. However, the data we do have indicates it will be challenging for the majority of students who have previously struggled with a junior course to then be successful with a load of four junior courses.

RQ3 asked if offering the junior courses twice a year would lower the department's time to graduation metric. With the one year of data we have, it seems unlikely that this curriculum change will significantly impact the department's time to graduation rates. Students who only fail a single junior course now have more options to retake it, but the majority of these students were able to recover to an on-time graduation prior to the curriculum change. Students who fail two junior courses in the fall again have more options to get back on track. However, these students are typically struggling more, and the increased course load needed to get back on track to an on-time graduation may prove even more problematic.

Overall, doubling junior course offerings seems to significantly increase faculty teaching load. In the AES department, there are 44 faculty that typically teach undergraduate courses with varying teaching loads, and roughly 25 required undergraduate course offerings per year. Offering junior courses twice a year requires 6 additional faculty members to cover the junior courses.

There are other factors that could be impacted by doubling course offerings that remained outside of the scope of this analysis. We did not look at the impact that offering junior courses twice a year may have on students who transfer into the AES program. We did not examine if offering courses twice a year would allow students who wish to take a semester off to pursue an internship/Co-op/study abroad opportunity. However, in either of these situations all students would have to synch up to take the required year-long senior projects course, which only starts in the fall. Note also we did not assess the changes in teaching or learning that might have occurred when junior courses were split from one large class of roughly 180 students to two smaller classes of 90 students.

Conclusions

Overall, this study highlights two key points:

1) Pre-requisite chains in a curriculum have a tremendous impact on student time to degree, and
2) Department policies can be instrumental in student success and faculty load.

The AES curriculum has 4 required sophomore courses that are currently offered once a year, 6 required junior courses, and one year-long required senior projects course. When the department doubled the junior courses to offer all 6 required courses both semesters, student progression through the curriculum was constrained by the sophomore and senior years. Students could not 'get ahead' in their sophomore year as sophomore courses that are pre-requisites for junior courses are only offered in the spring. All junior courses are pre-requisites for the year-long senior projects course which only enrolls in the fall. Therefore, students must recover from any junior course failures by the following fall.

A policy which allowed students to 'break' one pre-requisite chain and repeat a single failed junior course while taking senior projects was essential for student recovery to an on-time graduation. Without this policy, roughly 1 in 10 students would have had their graduation delayed an additional year. Studies by Heileman and Wigdahl also found that simplifying pre-requisite chains can reduce student time to degree metrics.[13] [14]

The department teaching load is constrained between a complex balance of number of times a course should be offered, number of faculty available to teach it, enrollment, and classroom space. Doubling the junior courses did result in a significant increase to the faculty teaching load. In comparison, the policy that allowed students to repeat a single failed course would have resulted in roughly a 5% increase in enrollment across all junior courses each year.

Future work will center on examining the link between sophomore courses and junior courses in terms of student success. We hope to understand if student in sophomore courses can act as a predictor for performance in junior courses. Additionally, the department hopes to expand the sophomore course offerings to twice a year. We plan to examine the number of students this will impact, and how the pre-requisite chains and offerings of sophomore courses can be optimized to allow multiple pathways through the curriculum.

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