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Data Analysis for First-Year Experience Redesign

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Abstract
This Complete Evidence-Based Practice Paper analyzes data on how the redesign of the first-year engineering course sequence has impacted student success and retention. The previous first-year sequence consisted of two courses that were three credits each and had to be taken sequentially. Each of these two courses combined multiple topics from different engineering disciplines. The new sequence consists of a collection of mini-courses that provide greater flexibility to the students and allow faculty to focus their teaching on their areas of expertise. The effects of this change on student success are analyzed and some broader implications of the mini-course approach are discussed.

Literature Review
This paper touches on two themes that have received considerable attention in the literature: redesign of the first-year engineering experience and student success/retention within engineering majors. The literature presents various motivations and methodologies for redesigning the first-year engineering experience. The goals of a first-year engineering experience are typically multifaceted and vary based on context. There is value in helping students understand what engineering is – exposing them to the breadth of majors available – and what it takes to be successful in the rigorous engineering coursework [1, 2]. It is not clear to what extent prospective students come in knowing which engineering specialty they want to pursue [3].

Concerning methodology, some redesign efforts have been guided by significant input from students, utilizing surveys or focus groups [3, 4]. Other redesign efforts have focused more on input from faculty [1]. In the work presented in this paper, student input was primarily anecdotal or pulled from comments in student course evaluations.

The motivation for redesigning the first-year experiences tends to include increasing retention, improving scalability as a program grows, reducing the number of credit hours committed to the first year, or a commitment to continuous improvement [1, 3, 4]. In this work, the faculty team redesigning the sequence was primarily concerned with student success and retention while also trying to increase flexibility for students.

Another theme that shows up in the literature is the extent to which the first-year engineering experience is multidisciplinary and how long students wait before attending discipline specific courses. Some programs might have only one multidisciplinary introductory course, while others have a common first-year experience [4]. It is worth noting that at Grand Valley State University, all engineering majors take the same courses for the first three semesters.

Retention of students in engineering is a longstanding and complex issue. Persistence in engineering is a combination of many factors including "cognitive, non-cognitive, and environmental variables" [5]. A student's decision to remain in engineering is most likely a combination of GPA/academic achievement, motivation, academic and social integration, and self-efficacy [6, 7]. There is some debate in the literature about what percentage of students leave engineering due to academic difficulty versus other factors [8].

Many innovative approaches have been pursued to increase retention of students in engineering. Examples include living and learning communities [9] and encouraging student ownership by asking students to design their own process to succeed [10].

Of particular interest to this work is the potential connection between a well-designed first-year experience and student retention [8]. This work is not directly concerned with influencing students' choices to stay in engineering, but instead is focused on efforts to scaffold students to achieve academic success so that they will not be required to leave the engineering program.

Introduction and Background

The engineering faculty at Grand Valley State University redesigned their first-year sequence several years ago. The new sequence launched in Fall 2020, and this is the first attempt at analyzing the effects of the new sequence post pandemic. The previous first-year sequence consisted of two courses that were each three credits and blended together multiple topics/disciplines. The first course in the sequence combined C programming and CAD/graphical communication. The second course in the sequence included an introduction to the design process, a cornerstone design project, tolerance stack analysis, and an introduction to GD&T. These courses made significant use of project-based learning (PBL) with these dissimilar topics often combined together in hand-on learning activities. This interdisciplinary approach was considered a novel strength at the time the previous sequence was introduced.

Overtime, several issues were identified with the previous sequence. Primarily, the pass rate for the first course was low, and, if students needed to repeat the course, they had to retake the entire three credits even if they were only deficient in one area. The somewhat unique interdisciplinary nature of the courses also made it difficult to award transfer credit. Students transferring into our program may have taken a programming course but not a CAD course or vice versa. As a result, students transferring in as juniors sometimes had to take one or both of these first-year courses. Another significant drawback was that faculty who were experts either in programming or engineering graphics were required to teach content outside their areas of expertise.

These factors formed the motivation to completely redesign the first-year sequence. The new sequence was designed with three primary goals: increasing student success, reducing the number of credit hours that needed to be repeated, and making it easier for incoming transfer students to receive credit for CAD or programming courses taken elsewhere.

Description of the Old Sequence

The old sequence consists of two courses:

- Intro to Engineering Design 1 (3 credits)
  - applied C programming
  - engineering graphics

- Intro to Engineering Design 2 (3 credits)
  - cornerstone design project
  - tolerance stack analysis
  - intro to GD&T

Description of the New Sequence

Because the previous sequence's issues were linked to it being highly interdisciplinary, the design of the new sequence tended in the opposite direction. The previous sequence consisted of two courses that were each three credits. The new sequence consists of five mini-courses that are each one or two credits. A guiding principle of the design of the new sequence was to match the previous sequence's total number of credits and contact hours as much as possible. The goal was to restructure essentially the same content in an improved format.

The new sequence is made up of the following mini-courses:

- Introduction to Engineering (1 credit)
- Engineering Graphics (1 credit)
- Applied Programming for Engineers (2 credits)
- Introduction to CAD/CAM (1 credit)
- Cornerstone Design (2 credits)

The first three courses are commonly taken concurrently in the first semester. CAD and cornerstone design are typically taken concurrently in the second semester. The cornerstone design course includes the design and prototyping of an electro-mechanical system, which typically takes the form of an Arduino-powered robot competing in an event of some kind.

Data analysis

The primary goal of this paper is to use institutional data to answer the following questions regarding the new first-year sequence's design goals:

- Has student success improved?
- Has more transfer credit been awarded for first-year courses?
- Has the number of repeated credit hours gone down?

In order to answer these questions, the authors requested institutional data regarding the first-year grades of all engineering students who have attempted either sequence. For each student, the data included their grades in all EGR 1xx courses (including grades for multiple attempts in each course). The data also includes each student's first math course as well as the first term when they attempted an engineering course.

For the purposes of this paper, a student is assumed to be successful if they pass the first-year sequence courses. Note that this work does not address students choosing to leave engineering without having academic difficulty; this work is focused on increasing the percentage of students who are academically successful in the first-year sequence. Student success is essentially defined as the pass rate of the first-year sequence: what percentage of students were able to complete the first-year sequence? In order to calculate this pass rate, it is necessary to quantify how many students began each sequence and how many students successfully completed each sequence. Since the old sequence consisted of only two courses that had to be taken in order, the number of students who attempted the first course became the denominator for the pass rate and the number of students passing the second course was the numerator. Because the new sequence was designed to make transferring into our program easier, the denominator for the pass rate was defined as the number of students who attempted any EGR 1xx course in the new sequence. The numerator was the number of students who pass the cornerstone design course, which is the last course in the sequence (it is permissible to take the cornerstone design course and the intro to CAD course concurrently). A grade of C or better is required to pass the foundation courses.

The results are summarized for different cohorts defined by math start in Table 1. The key result from Table 1 is that the new sequence has a lower pass rate for all math starts. That decrease in pass rate is smallest for students who are calc ready in their first semester. The pass rate for calc-ready students dropped from 62.9% under the old new sequence to 57.6% under the new sequence. Another important observation is that the pass rate for precalculus students dropped from 32.3% to 22.7% under the new sequence. It is concerning that the pass rate for students starting in precalculus is so low and essentially equivalent to that for students starting in algebra.

In order to assess the statistical significance of the differences in pass rate between the old and new sequences, a Z-test was used. The Z-test was chosen because we are comparing summative statistics for a large number of samples of binary data variables, which converge to a normal distribution for large sample sizes (central limit theorem).

The null hypothesis for this analysis is that the pass rates for the two sequences are the same and the p-value represents the likelihood that the null hypothesis is true. The p-values are listed in the last column of Table 1, and they are below 0.05 for all math cohorts, indicating that the decreased pass rates for the new sequence are all statistically significant.

Table 1: Comparison of pass rates for the old and new sequences separated by math start.

	old sequence			**new sequence**			
Math Start	**students completing**	**students attempting**	**pass rate (%)**	**students completing**	**students attempting**	**pass rate (%)**	**p-value**
Calc Ready	767	1220	62.9	294	510	57.6	0.042
Precalculus	62	192	32.3	56	247	22.7	0.024
College Algebra or Trig.	275	548	50.2	58	161	36	0.002
Algebra	95	270	35.2	31	137	22.6	0.01

One hypothesis regarding the decrease in pass rate for the new sequence is that the bar has been raised for students to pass the sequence. Because C programming and CAD were combined in one course under the old sequence, students course grades were a weighted average of various assignments and exams that involved multiple topics. This meant that a student who was doing poorly in programming could still pass the course by doing really well in CAD (or vice versa).

The new sequence now has a mini-course for each topic and students are required to earn a C in each mini-course. This detail was overlooked during the design of the new sequence so this is an unintended consequence of the redesign.

In order to further investigate this hypothesis that requiring a C in all mini-courses was contributing to the decrease in pass rate for the new sequence, the data was analyzed to try to estimate the number of students who would have passed if they were allowed to combine their grades in two of the mini-courses. We are trying to estimate the effects of allowing a student's CAD grade to pull up their programming grade, or vice verse. The histograms in Figures 1-3 are a key part of this analysis. The histograms show the grade distributions in one course for students who earned a D or D+ in another course. If a student earned a C+ or higher in one mini-course, that might have been enough to make up for earning a D or D+ in another mini-course if the grades were combined like they were under the old sequence. Note that the histograms are only for calc-ready students.

Figure 1 shows that 21 calc-ready students who earned a D or D+ in Applied Programming may have been able to pass under the old sequence based on earning a C+ or better in Intro to CAD. This constitutes 1.7% of calc-ready students attempting the new sequence. Note that Intro to Engineering Design 1 from the old sequence was a combination of Applied Programming, Intro to CAD, and some of the content from Engineering Graphics.

Similarly, Figure 2 shows that 14 calc-ready students who earned a D or D+ in Applied Programming earned a grade of C+ or higher in Engineering Graphics and might have been able to pass under the old sequence. This group accounts for 1.1% of calc-ready students attempting the new sequence.

Finally, Figure 3 shows that 11 calc-ready students who earned a grade of D or D+ in Engineering Graphics earned a grade of C+ or higher in Applied Programming and may have also passed under the old sequence. This group accounts for 0.9% of the calc-ready students attempting the new sequence.

So, depending on how the grades were combined, it is possible that 2-3% of calc-ready students who failed the new sequence would have been able to pass the old sequence. This would account for roughly half of the 5.2% decrease in pass rate for the new sequence for calc-ready students.

Data Analysis: Student Success Discussion

Based on Table 1 and the histograms of Figures 1-3, two conclusions can be drawn. First, the new sequence did not improve student success. In fact, it seems to have made it slightly worse. The second conclusion is that some portion of the decrease in pass rate for the new sequence is accounted for by inadvertently raising the bar for the first-year sequence: by separating each content area into its own mini-course, students must now earn at least a C in each area and can no longer use a strength in one area to cover up a weakness in another.

These results raise the question of what other factors may have contributed to the drop in student success. Possible contributors include:

- students not taking the one- to two-credit mini-courses as seriously as a three-credit course

- each instructor only seeing the students once per week
- students needing to navigate more deadlines, exams, and course websites
- affects of COVID on student preparation
- shifting demographics of incoming student population

Additional data would be needed to investigate these factors.

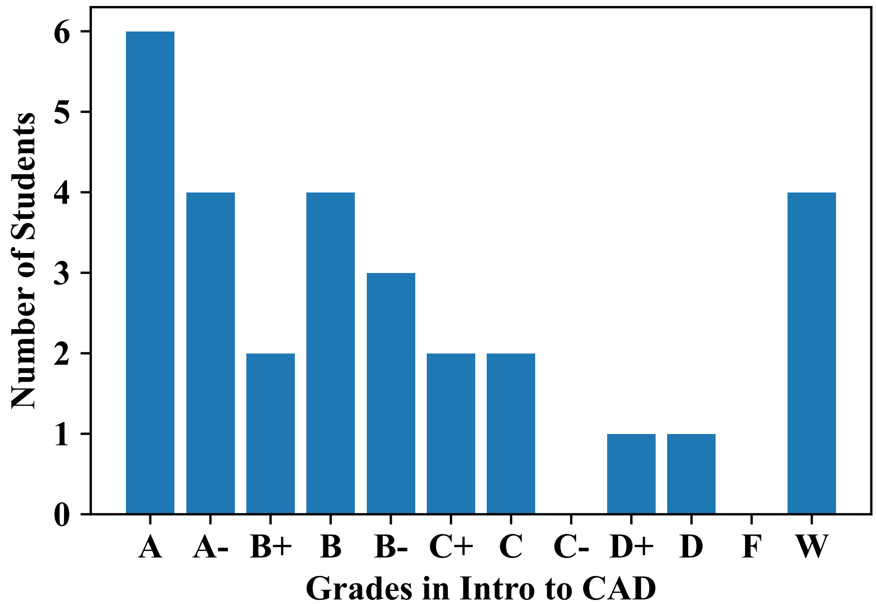

Figure 1: Histogram of grades earned in Intro to CAD by students who earned a D or D+ in Applied Programming for Engineers.

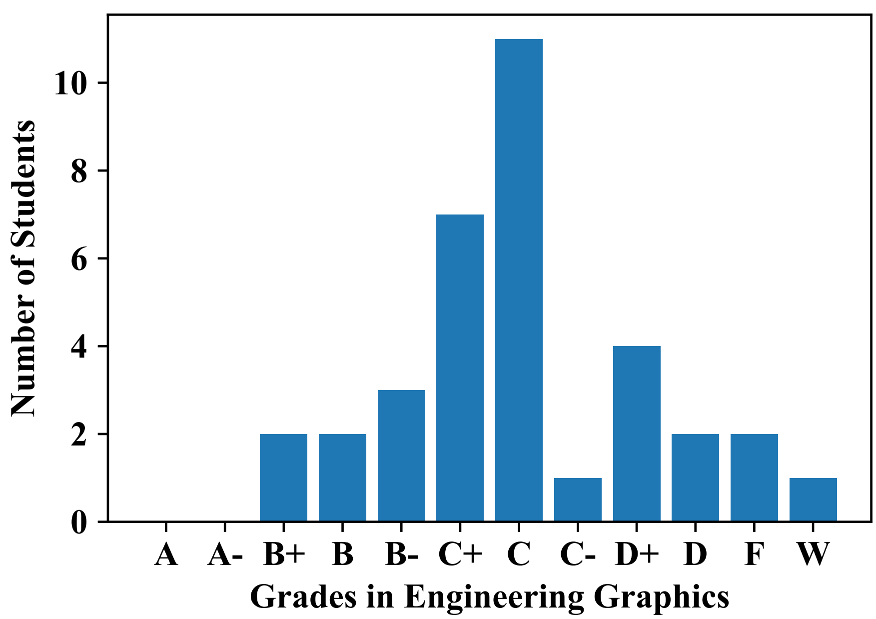

Figure 2: Histogram of grades earned in Engineering Graphics by students who earned a D or D+ in Applied Programming for Engineers.

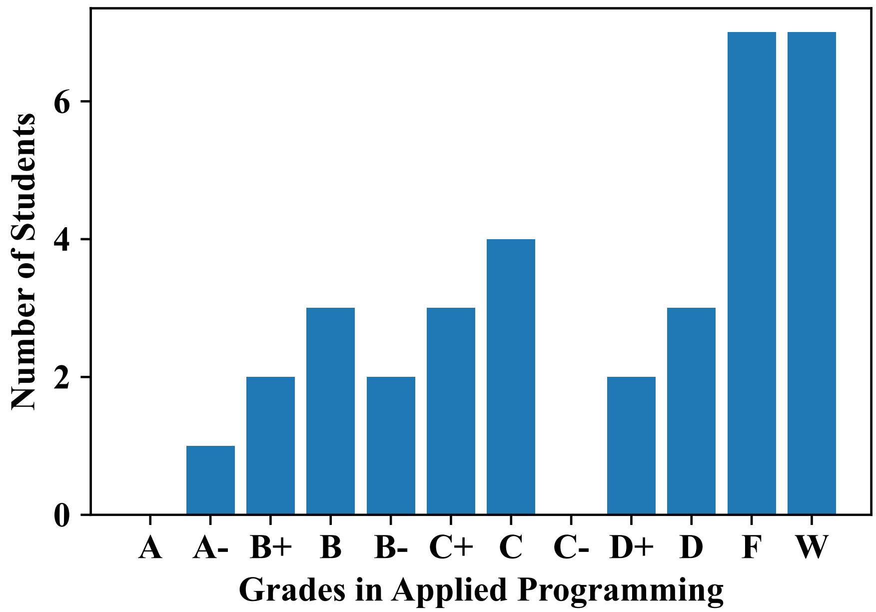

Figure 3: Histogram of grades earned in Applied Programming for Engineers by students who earned a D or D+ in Engineering Graphics.

Data Analysis: Transfer Credit

A second goal of the new sequence was to make it easier for students to transfer into our program. Table 2 shows that this goal was met: 78 transfer grades have been awarded for courses in the new sequence while only one transfer grade had ever been awarded under the old sequence. Note that 1055 students have attempted the new sequence, so transfer credit has been awarded to roughly 7% of those students. Under the old sequence, it was very difficult for incoming transfer students to get credit for the Intro to Engineering Design courses. The unique blend of interdisciplinary content made it very unusual for students to take a similar course or a combination of courses that covered the same content elsewhere. As Table 2 shows, transfer credit for Intro to Engineering Design 1 was only awarded once and no transfer credit for the second course was ever awarded. In contrast, reasonable numbers of students have received transfer credit for the mini-courses in the new sequence. This has reduced one area of complaint for incoming transfer students; however, the problem might still persist with Cornerstone Design. So far, we have not had an incoming transfer student who took a comparable cornerstone design course involving an Arduino-controlled, electro-mechanical project. We have had students submit transfer requests for courses with projects that are similar, but they often do not go far enough and are missing topics such as state machines or CNC machining.

Data Analysis: Repeated Credit Hours

The third question being analyzed is whether or not the new sequence reduced the credit hours being repeated. One complaint under the old sequence is that if a student failed Intro to Engineering Design 1, they had to retake the entire course even if they were doing well in one area. A student who did well in CAD but failed programming, for example, still had to retake the entire course. Table 3 presents retake data for the old sequence. For example, for Intro to Engineering Design 1, 12.82% of students repeated the course. This leads to an average of 0.38

Table 2: Number of transfer grades awarded for each course in the old and new sequence.

Old Sequence Courses	Transfer Grades Awarded	New Sequence Courses	Transfer Grades Awarded
Intro to Eng. Design 1	1	Engineering Graphics	44
Intro to Eng. Design 2	0	Applied Programming	6
		Intro to CAD	28
		Cornerstone Design	0

repeated credit hours per student who attempted the course. Engineering Design 2 had a repeat rate of 7.4%, leading to an average of 0.22 repeated credit hours per student. Adding these two together leads to a total of 0.60 average repeat credit hours per student under the old sequence.

Table 4 shows the same data for the new sequence. Repeat rates for the new sequence are quite similar to those of the old sequence, and the total average repeat credit hours per student is identical to that of the old sequence.

Table 3: Repeat credit hour analysis for the old sequence.

Course	Total Attempts	Repeats	Repeat Rate	Credit Hours	Repeated Credit Hours	Repeated Credit Hours per Student
Intro to Eng. Design 1	2723	349	12.82%	3	1047	0.38
Intro to Eng. Design 2	1757	130	7.40%	3	390	0.22
					Total	0.60

Table 4: Repeat credit hour analysis for the new sequence.

Course	Total Attempts	Repeats	Repeat Rate	Credit Hours	Repeated Credit Hours	Repeated Credit Hours per Student
Engineering Graphics	1238	143	11.55%	1	143	0.12
Applied Programming	1011	133	13.16%	2	266	0.26
Intro to CAD	871	83	9.53%	1	83	0.10
Cornerstone Design	574	37	6.45%	2	74	0.13
					Total	0.60

Implications for the Wider Community

While the data analysis presented is specific to our institution, one generalizable implication is that the mini-course approach has its benefits and drawbacks. The faculty have suspicions that students do not take a one-credit engineering course as seriously as they should; and the students complain that the engineering graphics courses are too much work for one credit. Breaking the old three-credit courses into multiple mini-courses means that the faculty have to teach more sections for the same number of teaching credits. This means learning more students' names and having to answer emails from a larger number of students. From the students' perspective, taking multiple mini-courses means having to keep track of more deadlines, taking more exams, and learning the expectations of more instructors. In the process, workloads seem to have crept up for students and faculty alike. The benefits of the mini-course approach include providing more flexibility to students and additional pathways for students to transfer into our program.

A smaller implication of this work is that any curriculum change, no matter how small, can have unintended consequences. It did not occur to the team of faculty designing the new sequence that the bar was being raised by requiring students to earn a grade of C in each area independently. This change can be problematic for mini-courses that are outside of a student's area of interest: EE's taking Engineering Graphics or ME's taking Applied Programming. When combined into a single course in the old sequence, there was significant faculty effort and collaboration to integrate the different skills presented, but now that the topics are separated, instruction is trending toward more traditional siloed approaches.

Future Work

The data analysis for this paper has raised several additional questions that the authors plan to address in the future. Data will continue to be collected longitudinally to control for pandemic related effects. An investigation is needed to increase understanding of low success rates for students who start in precalculus. Note that the precalculus pass rate was an issue even under the old sequence (see Table 1). Additional data will be requested that includes the math and physics grades of the students in an attempt to understand when students leave engineering and what factors contribute to their departure.

Additionally, longitudinal data will be used to study the effectiveness of another recent change to the first-year sequence. The applied programming course continues to be a challenge for some students. This course can now be stretched over two semesters if the students choose to do so; however, this change was too recent to include in this work.

Conclusions

In conclusion, the success of this first-year redesign is unclear. The redesign had three goals: increase student success, make it easier to transfer into our program, and decrease the number of credit hours being repeated. Only one of the three goals has clearly been met: it is now easier for students to receive transfer credit when entering our program. The average number of repeated credit hours per student is essentially unchanged. The pass rate for the new sequence is slightly lower than the old sequence – student success has been negatively affected. One cause for the decrease in pass rate is that the new sequence inadvertently raised the bar by requiring students to earn grades of C or better in each mini-course, such that a student who is weak in programming can no longer offset that by being really strong in CAD, or vice versa. This decrease in pass rate may mean that the students who make it through the new first-year sequence are slightly stronger than they were under the old sequence and may be better prepared for later courses involving programming or CAD.

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