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An Assessment of Prerequisite Course Requirements and Their Correlations to Student Success in the Mechanical Engineering Curriculum

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Introduction

The Mechanical Engineering Department at Ohio Northern University (ONU) is undergoing curricular revisions in the sophomore and junior years to better align with industry needs. As part of this effort, course prerequisite requirements were analyzed using curricularanalytics.org, which is an online tool that can help assess curriculum structure, identify bottlenecks, and evaluate the impact of course dependencies and prerequisites on student progression and success. This tool also evaluates each course in the curriculum in terms of blocking factor (a measure to which that course acts as a gateway to later coursework), delay factor (the length of the longest pathway involving a given course), centrality (a measure of how many prerequisites the course involves as well as how many courses involve the target as a prerequisite), and structural complexity (the impact of the course on student progression). The complexity metric is then aggregated by term and across the program.

The mapping of the revised curriculum is depicted in Figure 1. The numerical values for each course are the complexity metric as calculated by CurricularAnalytics and the lines indicate the prerequisite chains. Notably not captured is that the Capstone 1 requirement is the completion of “two of three tracks” where Heat Transfer, Controls, and the combination of Machine Components and Kinematics courses represent the three track end conditions. This permits some degree of flexibility beyond what is captured in the model, as the third unfinished track is able to be delayed to the senior year.

As demonstrated in Figure 2, the longest prerequisite chain in the curriculum runs through the Dynamics/Dynamic Systems course sequence, known to be a frequent bottleneck for on-time graduation. This is exacerbated by the requirement that students must earn a grade of C in Statics to proceed to Dynamics, and a grade of C in Dynamics to advance to Dynamic Systems Modeling (a differential-equation-based modeling course). Additionally, Dynamic Systems Modeling requires passing grades in both Differential Equations and Electric Circuits. Although students who struggle with these prerequisite courses have opportunities to catch up, this often delays Dynamic Systems Modeling (and its successor, Controls) to the senior year, or requires additional time and financial investment through summer or J-term courses. These delays may result in overloaded senior-year schedules and limit students' ability to apply foundational knowledge in their senior courses and capstone projects.

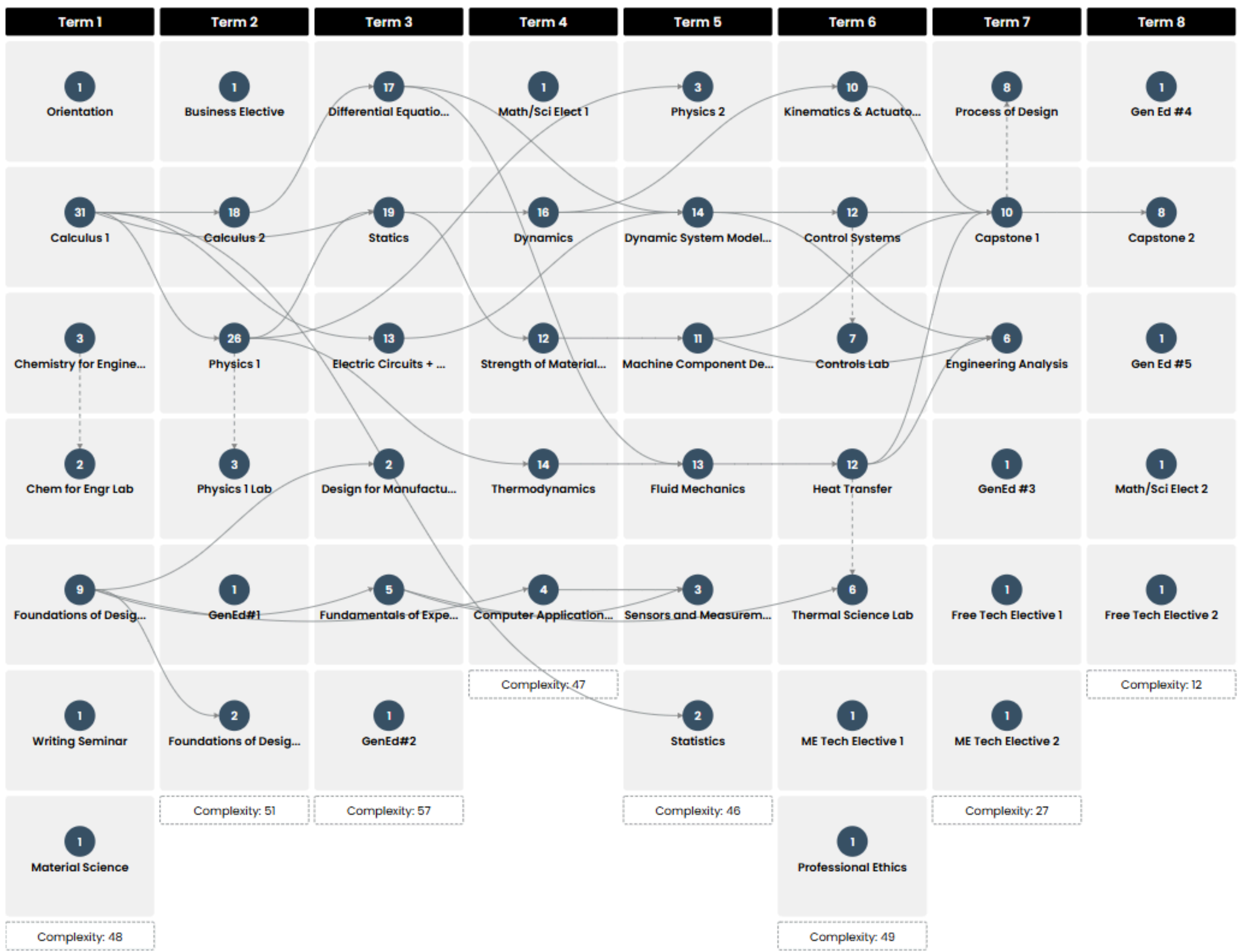

Figure 1: Curriculum map, as analyzed by CurricularAnalytics.

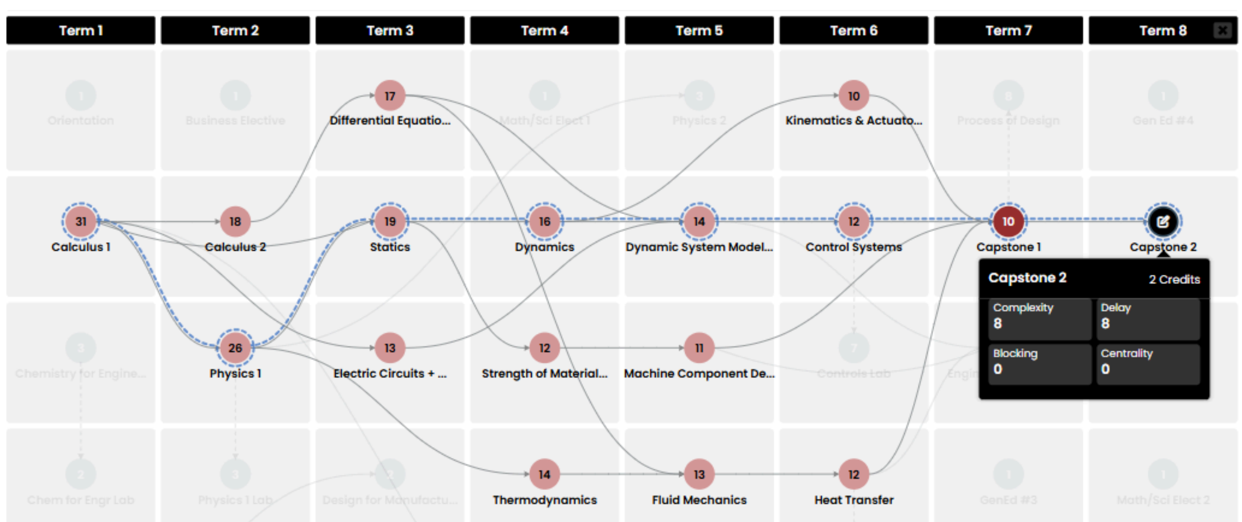

Figure 2: Partial curriculum map, highlighting the mechanics, dynamic-systems, and thermal-science tracks.

Table 1 captures the analytics metrics for the Top eight courses (out of 48 total in the curriculum) in terms of complexity score. They include the predictable entry-points (calculus, differential equations, physics) as well as courses in two of the core tracks, including both Dynamics and Dynamic System Modeling. This data shows that, not only is the dynamic-systems track challenging to get through (requiring a higher grade for prerequisites), these courses are also among the most central to the curriculum and most potentially disruptive if not passed on time. The thermal-science track ranks similarly in terms of complexity, but not only is it less central to the overall curriculum, it does not require the same C requirement to progress. This begs the question of whether the additional C requirement is necessary for the dynamic-systems track or if, given the impact of that track on overall curricular progression, that requirement should be relaxed.

Table 1: CurricularAnalytics Metrics for Selected Courses.

	Complexity		Blocking		Delay		Centrality	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Calculus 1	31	1	23	1	8	1	0	18
Calculus 2	18	4	11	4	7	10	51	9
Differential Equations	17	5	10	5	7	11	51	10
Physics 1	26	2	18	2	8	2	95	4
Statics	19	3	11	3	8	3	117	2
Dynamics	16	6	8	6	8	4	80	5
Thermodynamics	14	7	7	7	7	12	26	13
Dynamic System Mod.	14	8	6	9	8	5	100	3

Research Framing and Literature Basis

The literature on assessment of prerequisite courses in engineering is quite limited. Danesh-Yazdi, et al. [1] examined if success in Statics was affected by whether Physics was a prerequisite or corequisite. Wilck, et al. [2] studied whether time since taking a prerequisite impacted success in a quality control course. Karimi and Manteufel [3] assessed grades between a two-course sequence in thermodynamics. Wingate, et al. [4] assessed programming prerequisites and interventions or success in an aerospace curriculum. Finally, Efimba and Smith [5] looked into the relationship between achievement and retention versus prerequisite knowledge. Similar work has been done outside of engineering, e.g., [6], [7]. In all of the above studies, either quantitative statistics were not performed, a singular prerequisite was assessed using mixed methods, or multiple prerequisite conditions were compared.

In this paper, the question is not how effective the prerequisite courses are, or whether they are warranted, but rather how important the more stringent requirement of a C is in the dynamic-systems track. Since all of the courses in question have multiple prerequisites and successors (see below), the analysis will rely purely on the final grades of each course, and the degree to which they are correlated.

The primary focus of this paper's analysis is on the prerequisite courses in the dynamic-systems track requiring a grade of C or better. In Mechanical Engineering at ONU, the Dynamic Systems Modeling course requires a C in Dynamics, as well as passing grades in Differential Equations and Electric Circuits. The Dynamics course requires a C in Statics, as well as a passing grade in Calculus 2. In looking at the two courses requiring a C to progress, Statics and Dynamics, it is also useful to look at their other successor courses. In addition to Dynamics (C or better), Statics is a prerequisite for Strength of Materials (passing grade). In addition to Dynamic Systems Modeling (C or better), Dynamics is a prerequisite for Kinematics and Actuators (passing grade). For greater context, similar analysis will be performed on the thermal-science track, in which the Fluid Mechanics course requires passing grades in both Thermodynamics and Differential Equations. These relationships are illustrated in Figure 3.

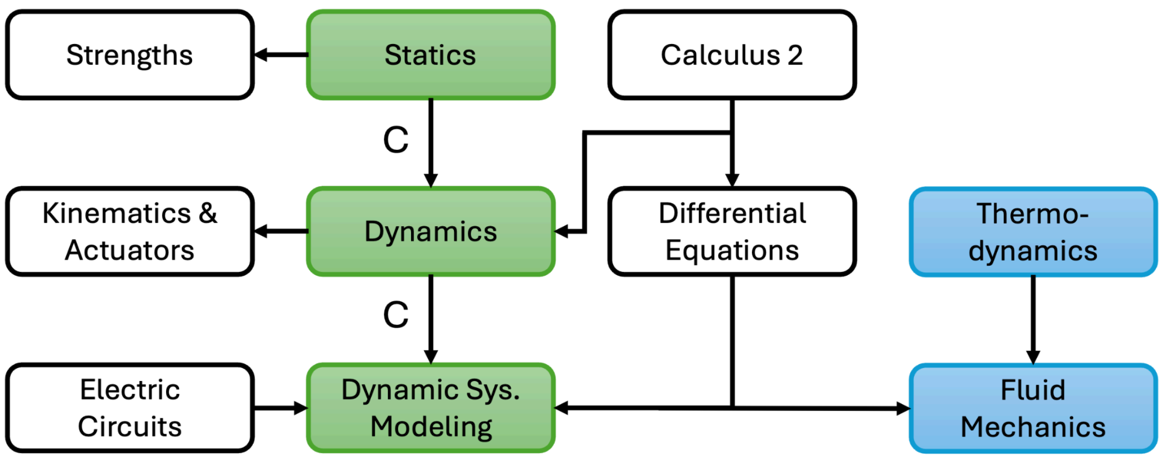

Figure 3: Prerequisite mappings for dynamic-systems and thermal-science courses. Arrows indicate a passing grade prerequisite requirement, unless noted.

This paper aims to assess the correlations between performance in the prerequisite courses and success in Dynamics and Dynamic Systems. The existence of correlations will be statistically assessed using Chi-squared tests, and the degree of correlation will be quantified via Cramer's V. It is expected that Dynamics will have the highest correlation with Dynamic Systems Modeling, and Statics will have the highest correlation with Dynamics, versus all other prerequisite-successor course pairings.

Finally, the results from the dynamic-systems track will be compared to the thermal-science track, where no "C" prerequisite rule exists. The findings will help guide potential modifications to the prerequisite structure for the dynamic-systems track at ONU to alleviate bottlenecks while maintaining academic rigor.

Methods

Course letter grades (A, B, C, D, F, W) were obtained from the University's Institutional Research office for all courses in the prerequisite chains described above from Fall 2014 to Fall 2023. All data collection and analysis procedures were approved by the University's Institutional Review Board prior to the start of this project. ONU does not award +/- grades. During the

COVID-19 pandemic, students were offered a modified pass/fail grading option for the Spring 2020 semester. If this option was taken, grades of A-C mapped to “pass” (P), grades of D mapped to “low pass” (LP), and grades of F mapped to “not passed” (NP). For the purposes of this study, LP was counted as D, NP was counted as F, and students earning a P were dropped from any analysis for that course. Students who withdrew from a course (W) were also dropped from any analysis for that course. To aid in numerical analysis, course grades were converted to their GPA equivalents: A=4, B=3, C=2, D=1, F=0. For consistency, the grade from the first attempt of a course was used.

The importance of prerequisite courses was assessed by comparing the correlations of course grades for each prerequisite pairing (e.g., Statics-Dynamics vs Calc2-Dynamics). Since the data are categorical, a Chi-Squared test was performed on contingency tables for each course pair to determine whether the course grades were correlated ($\alpha = 0.05$) [8]. For interpretation, a statistically-significant Chi-squared statistic ($p < \alpha$) would reject the null hypothesis that the two courses’ grades are independent, thus they are correlated. Since the course grades are paired by student, it is expected that all course pairs will be correlated to some extent. Therefore, a Cramer’s V correlation was also calculated to determine the strength of correlation between the course pairs [9]. Based on the number of grades for a course (A-F), which determines the degrees of freedom for the Cramer’s V calculation, a standard guideline states that a value above 0.25 is a “large effect,” meaning the two datasets are highly correlated [10]. It would be expected that any course and its prerequisite would be highly correlated, but the difference in Cramer’s V between different course pairs can provide insight into which courses may be more important than others in the prerequisite structure. Paired t-tests were also utilized ($\alpha = 0.05$) to determine whether the mean course grades for each pairing were statistically different or not.

The analyses described above were performed on the following course pairs:

1. Dynamic Systems Modeling versus its prerequisites
    a. vs. Dynamics ($n = 458$)
    b. vs. Differential Equations ($n = 427$)
    c. vs. Electric Circuits ($n = 483$)
2. Dynamics versus its prerequisites
    a. vs. Statics ($n = 444$)
    b. vs. Calculus 2 ($n = 362$)
3. Dynamics versus its successors
    a. vs. Dynamic Systems Modeling (repeat of course pair 1.a)
    b. vs. Kinematics and Actuators ($n = 453$)
4. Statics versus its successors
    a. vs. Dynamics (repeat of course pair 2.a)
    b. vs. Strengths ($n = 456$)
5. Fluid Mechanics versus its prerequisites
    a. vs. Thermodynamics ($n = 465$)
    b. vs. Differential Equations ($n = 423$)

Results

For each course pair presented above, the following data are presented in tabular form:

- Number of students (only students with valid grades from ONU in both courses are included)
- Mean grade for each course given in terms of GPA scale
- Paired t-test results (p-value) comparing the two course grades
- Chi^2 results (p-value), which gives a test statistic for the correlation between course grades
- Cramer's V to quantify the amount of correlation between course grades

Contingency tables for each course pair are also presented in the Appendix for reference.

Results are presented for Dynamic Systems Modeling and its prerequisites (Table 2), Dynamics and its prerequisites (Table 3), Dynamics and its successors (Table 4), Statics and its successors (Table 5), and Fluid Mechanics and its prerequisites (Table 6). Data were presented in this manner to more easily compare the two courses requiring a grade of C to advance in the dynamic-systems track (Statics and Dynamics) to the prerequisites outside this track (Tables 2 and 3), and to their successor courses outside this track (Tables 4 and 5). Table 6 provides the same data for the thermal-science track (Fluid Mechanics and its prerequisites), which do not require a C for any prerequisites.

Looking at all of the course pairings, it is apparent that the grades for each are highly correlated (Chi^2 $p << 0.001$). Investigating the amount of correlation using Cramer's V, it is apparent that Dynamic Systems Modeling is more correlated with Dynamics than any other prerequisite course (Table 1). Cramer's V for Electric Circuits is close to Dynamics, but the mean grade for Circuits is significantly lower than Dynamic Systems Modeling (t-test $p << 0.001$), while grades for Dynamic Systems Modeling and Dynamics are statistically similar (t-test $p = 0.540$).

Likewise, Dynamics is more correlated with Statics than its other prerequisite (Table 3). In the opposite direction, Dynamics is more correlated with Dynamic Systems Modeling than its other successor (Table 4). Statics is similarly correlated with both of its successors (Table 5). Finally, Fluid Mechanics has a similar correlation with both of its prerequisites (Table 6), which are both much lower than the Statics-Dynamics and Dynamics-Dynamic Systems correlations.

A heat map was created for the Cramer's V results in order to more easily compare the degree of correlation between the various course pairings (Figure 4). The columns of the table consist of the courses in the dynamic-systems track (Dynamic Systems Modeling, Dynamics, and Statics), plus Fluid Mechanics for comparison. The rows consist of the prerequisites and pertinent successors for those courses (Dynamics, Differential Equations, Electric Circuits, Statics, Calculus 2, Kinematics and Actuators, Strength of Materials, and Thermodynamics). The heat map follows the RGB colormap, where green is high and red is low. Note that all of the comparisons described in the methods and shown in the tables above are between a course and its prerequisites/successors, hence there are many blank spaces in the heat map. Visually, with the one exception of Statics-Strengths, the dynamic-systems courses are all more correlated to each other than the rest.

Table 2: Dynamic Systems Modeling (DSM) vs. prerequisites [Dynamics (Dyn), Differential Equations (DE), and Electric Circuits (EC)]. For each course pair: number of students (n), mean course grades, p-values for paired t-test and Chi^2 test, and Cramer's *V* are given.

Course Pair	**n**	**DSM Mean**	**Pre. Mean**	**t-test *p***	**Chi^2 *p***	**Cramer's *V***
DSM vs Dyn	458	2.801	2.777	0.540	2.32E-49	0.404
DSM vs DE	427	2.850	2.536	9.96E-09	6.00E-25	0.311
DSM vs EC	483	2.766	2.516	3.69E-09	7.06E-50	0.385

Table 3: Dynamics (Dyn) vs. prerequisites [Statics (Stat) and Calculus 2 (C2)]. See Table 1 caption for data explanation.

Course Pair	**n**	**Dyn Mean**	**Pre. Mean**	**t-test *p***	**Chi^2 *p***	**Cramer's *V***
Dyn vs Stat	444	2.791	2.788	0.958	4.96E-51	0.412
Dyn vs C2	362	2.812	2.707	0.073	4.93E-15	0.271

Table 4: Dynamics (Dyn) vs. successors [Dynamic Systems Modeling (DSM) and Kinematics and Actuators (KA)]. See Table 1 caption for data explanation.

Course Pair	**n**	**Dyn Mean**	**Succ. Mean**	**t-test *p***	**Chi^2 *p***	**Cramer's *V***
Dyn vs DSM	458	2.777	2.801	0.540	2.32E-49	0.404
Dyn vs KA	453	2.779	2.731	0.285	6.33E-24	0.298

Table 5: Statics (Stat) vs. successors [Dynamics (Dyn) and Strengths (Str)]. See Table 1 caption for data explanation.

Course Pair	**n**	**Stat Mean**	**Succ. Mean**	**t-test *p***	**Chi^2 *p***	**Cramer's *V***
Stat vs Dyn	444	2.788	2.791	0.958	4.96E-51	0.412
Stat vs Str	456	2.752	2.798	0.280	8.84E-53	0.414

Table 6: Fluid Mechanics (FM) vs. prerequisites [Thermodynamics (TD) and Differential Equations (DE)]. See Table 1 caption for data explanation.

Course Pair	**n**	**FM Mean**	**Pre. Mean**	**t-test *p***	**Chi^2 *p***	**Cramer's *V***
FM vs TD	465	2.897	3.043	5.40E-04	1.01E-24	0.303
FM vs DE	423	2.924	2.541	1.63E-11	7.86E-20	0.282

	DSM	Dyn	Stat	FM
Dyn	0.404		0.412	
DE	0.311			0.282
EC	0.385			
Stat		0.412		
C2		0.271		
KA		0.298		
Str			0.414	
TD				0.303

Figure 4: Heat map of Cramer's V results for Dynamic Systems Modeling (DSM), Dynamics (Dyn), Statics (Stat), and Fluid Mechanics (FM) compared to their prerequisites and successors: Dynamics, Differential Equations (DE), Electric Circuits (EC), Statics, Calculus 2 (C2), Kinematics and Actuators (KA), Strength of Materials (Str), and Thermodynamics (TD). Higher values are green and lower values are red.

Discussion

The comparisons in this study are derived from the same students taking related courses, so it is no surprise that every course pair listed is statistically correlated (Chi^2 $p << 0.001$). Further, according to Cramer's V, they are all highly correlated ($V \geq 0.25$). It could be argued that this is to be expected, otherwise the value of these prerequisite requirements might be called into question. While all course pairs were highly correlated, the degree to which each pairing is correlated can be assessed by comparing the Cramer's V results across the pairs.

Focusing first on Dynamics, which requires a grade of C to move into Dynamic Systems Modeling, it can be seen that Dynamics is more correlated with Dynamic Systems than any of the other prerequisites ($V = 0.404$, Table 2). Further, the mean grades for each of these courses is statistically similar (t-test $p = 0.540$), suggesting that a student might tend to get the same grade in both courses. Recall that these results are based on first attempts at each course. Therefore, this connection between course grades is even stronger when considering any students with a D or F in Dynamics would have repeated the course before moving into Dynamic Systems Modeling. Electric Circuits is close behind Dynamics in terms of correlation with Dynamic Systems Modeling ($V = 0.385$, Table 2). However, the Circuits Mean grade is statistically lower than Dynamic Systems (t-test $p << 0.001$). This would indicate that while the grades are almost as highly-correlated here, students perform better in Dynamic Systems Modeling than Electric Circuits. Similar arguments can be made for Differential Equations ($V = 0.311$). Considering these relationships between Dynamic Systems Modeling and all of its prerequisite courses, it seems reasonable to require a C in Dynamics, but not the other prerequisites, and apparently beneficial for student success in Dynamic Systems Modeling.

The question then arises if a C in Dynamics should be required for its other successor course, Kinematics and Actuators. The results suggest that Dynamics is more highly correlated with Dynamic Systems Modeling ($V = 0.404$) than with Kinematics and Actuators ($V = 0.298$,

Table 3). This result suggests that students with a D or F in their first attempt of Dynamics are not as likely to receive a D or F in Kinematics and Actuators, and the more stringent requirement on Dynamics by Dynamic Systems Modeling may be appropriate.

The second elevated prerequisite requirement in the dynamic-systems track at ONU is the requirement of a grade of C in Statics to move into Dynamics. Statics is more correlated with Dynamics ($V = 0.412$, Table 3) than its other prerequisite, Calculus 2 ($V = 0.271$). Statics is also more correlated to Dynamics than Dynamics is to Dynamic Systems Modeling. This correlation, combined with the fact that the mean grades of Statics and Dynamics are extremely similar (t-test $p = 0.958$), gives confidence that the requirement of a C in Statics to move into Dynamics is appropriate.

In addition to Dynamics, Strengths is a successor course for Statics. Statics grades are very-similarly correlated with Strengths ($V = 0.414$, Table 4) as they are with Dynamics ($V = 0.412$). This result might suggest that a C should also be required in Statics before moving into Strengths. Anecdotally, when looking at the contingency tables for Dynamics-Statics (Table A-4) and Strengths-Statics (Table A-7), it does appear that it is slightly more likely for a student to raise their grade from Statics to Strengths more so than Statics to Dynamics. Further analysis would be needed to determine the effects of those students who took Strengths after earning a D in Statics, but before retaking Statics and earning a C or better. Looking at the raw data, of the 58 students who received a D or F in their first attempt at Statics, 43 ended up repeating Statics and earning a C or better concurrent with their first attempt at Strengths, and two earned a C or better in a later semester. Since every student must have earned a C or better in Statics before taking Dynamics, and only 13 earned a C in Statics *before* taking Strengths, the comparison between these two courses may be skewed in favor of *not* recommending a C in Statics before moving into Strengths.

Finally, a comparison to the other primary course sequences in the Mechanical Engineering program are warranted. In the thermal-science track, Thermodynamics is a prerequisite for Fluid Mechanics. While these courses were correlated ($V = 0.303$, Table 6), the correlation was not much higher than between Fluid Mechanics and its second prerequisite, Differential Equations ($V = 0.282$). Further, the correlation between Fluid Mechanics and Thermodynamics is lower than the correlations in the dynamic-systems track. While not directly presented in the results, the progression from Dynamics to Kinematics and Actuators is part of the third (and final) major track of courses in Mechanical Engineering at ONU, and was discussed above (Table 4).

Conclusion

This paper presented correlation data for two courses, Statics and Dynamics, and each of their prerequisite and successor courses, as motivated by the current requirement of a C in both to progress in the dynamic-systems track of courses for the Mechanical Engineering program at Ohio Northern University. Aside from one course pair, the courses requiring a C to move on in this course sequence proved to have the highest correlations, suggesting a greater importance to their successor courses than the other prerequisites. Further, these correlations were higher than those of the other course sequences in the Mechanical Engineering curriculum. The results of this paper suggest that the more stringent requirements of a C to move from Statics to Dynamics, and from Dynamics to Dynamic Systems Modeling, are appropriate.

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Appendix

Contingency tables for all course pairings listed in the Methods section.

Table A-1**:** Contingency table for student grades in Dynamic Systems Modeling (DSM) and Dynamics (Dyn).

Count	**DSM Grade**					
Dyn Grade	**4**	**3**	**2**	**1**	**0**	**Grand Total**
4	91	15	4			**110**
3	36	80	53	7	2	**178**
2	7	49	62	16	3	**137**
1		6	12	4	2	**24**
0			2	4	3	**9**
Grand Total	**134**	**150**	**133**	**31**	**10**	**458**

Table A-2: Contingency table for student grades in Dynamic Systems Modeling (DSM) and Differential Equations (DE).

Count	**DSM Grade**					
DE Grade	**4**	**3**	**2**	**1**	**0**	**Grand Total**
4	86	37	12			**135**
3	27	43	18	3	1	**92**
2	9	39	41	8	3	**100**
1	4	18	36	7	2	**67**
0	2	8	16	6	1	**33**
Grand Total	**128**	**145**	**123**	**24**	**7**	**427**

Table A-3: Contingency table for student grades in Dynamic Systems Modeling (DSM) and Electric Circuits (EC).

Count	**DSM Grade**					
EC Grade	**4**	**3**	**2**	**1**	**0**	**Grand Total**
4	86	25	2	1		**114**
3	36	56	32	4	2	**130**
2	13	54	71	8	1	**147**
1	1	17	34	19	4	**75**
0		4	4	6	3	**17**
Grand Total	**136**	**156**	**143**	**38**	**10**	**483**

Table A-4: Contingency table for student grades in Dynamics and Statics (Stat).

Count	Dynamics Grade					
Stat Grade	4	3	2	1	0	Grand Total
4	88	45	8			141
3	11	83	45	3		142
2	7	35	53	9	2	106
1	4	7	17	7	1	36
0		1	8	5	5	19
Grand Total	110	171	131	24	8	444

Table A-5: Contingency table for student grades in Dynamics and Calculus 2 (C2).

Count	Dynamics Grade					
C2 Grade	4	3	2	1	0	Grand Total
4	59	37	18	1	1	116
3	21	51	23	5		100
2	10	38	33	6	1	88
1	1	15	17	4	3	40
0	1	1	12	2	2	18
Grand Total	92	142	103	18	7	362

Table A-6: Contingency table for student grades in Kinematics and Actuators (KA) and Dynamics (Dyn).

Count	KA Grade					
Dyn Grade	4	3	2	1	0	Grand Total
4	71	31	6	1		109
3	33	72	57	10	3	175
2	11	48	55	17	6	137
1		5	12	6	1	24
0		2	4	1	1	8
Grand Total	115	158	134	35	11	453

Table A-7: Contingency table for student grades in Strengths and Statics (Stat).

Count	Strengths Grade					
Stat Grade	**4**	**3**	**2**	**1**	**0**	**Grand Total**
4	93	41	6	1		**141**
3	22	76	36	6	1	**141**
2	8	46	46	14	2	**116**
1		9	19	7	1	**36**
0		3	6	5	8	**22**
Grand Total	**123**	**175**	**113**	**33**	**12**	**456**

Table A-8: Contingency table for student grades in Fluid Mechanics and Thermodynamics (TD).

Count	Fluid Mech. Grade					
TD Grade	**4**	**3**	**2**	**1**	**0**	**Grand Total**
4	88	81	17			**186**
3	16	92	48	6	1	**163**
2	1	43	28	3		**75**
1		7	20	4	1	**32**
0		3	4	2		**9**
Grand Total	**105**	**226**	**117**	**15**	**2**	**465**

Table A-9: Contingency table for student grades in Fluid Mechanics and Differential Equations (DE).

Count	Fluid Mech. Grade					
DE Grade	**4**	**3**	**2**	**1**	**0**	**Grand Total**
4	69	57	9			**135**
3	21	52	16	2		**91**
2	5	52	37	4		**98**
1	6	29	25	6		**66**
0	1	13	16	2	1	**33**
Grand Total	**102**	**203**	**103**	**14**	**1**	**423**