

Analyzing the Effect of Bottleneck Courses on Time to Graduation

by

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# Abstract

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Curricular analytics is a field of study commonly used to study curricula within a university, or to create models that produce useful data about certain curricula. This thesis will investigate four different academic programs, two highly structured and two less structured, and apply basic techniques from curricular analytics to analyze whether the “bottleneck” courses — defined as one with three or more other courses directly or indirectly requiring it as a prerequisite – within the major are causing students to take longer than four years or change majors. We will answer the question of “Are the determined “bottleneck” courses the courses students are more likely to withdraw from or fail?”, and “Are students within a highly structured academic program with more “bottleneck” courses more likely to change majors?”

## Acknowledgments

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# Table of Contents

<b>Chapter 1: Introduction</b> . . . . .	<b>1</b>
<b>Chapter 2: Background</b> . . . . .	<b>2</b>
<b>Chapter 3: Academic Programs</b> . . . . .	<b>5</b>
Public relations . . . . .	6
Criminal justice . . . . .	8
Interior design . . . . .	10
Physical education . . . . .	11
<b>Chapter 4: Description of Data</b> . . . . .	<b>14</b>
<b>Chapter 5: Analysis of Data</b> . . . . .	<b>16</b>
Are the “bottleneck” courses we identified what students are withdrawing from and failing most? . . . . .	16
Are highly structured academic programs with more “bottleneck” courses causing students to switch majors? . . . . .	18
<b>Chapter 6: Conclusion</b> . . . . .	<b>21</b>
Limitations . . . . .	21
Future Investigations . . . . .	22

## Chapter 1: Introduction

Beginning with the question of if “bottleneck” courses have an impact on time to degree, we chose to investigate and apply basic techniques from curricular analytics to four academic programs within a large four year university in the Southeast. Curricular analytics, a subfield of learning analytics, allows us to investigate curricula and design degree plans that give students the best chance of graduating in four years, quantify the complexity of different curricula, identify bottlenecks within programs, and reform curricula based on data we gather [1].

On recommendation from the academic advisor team at the university, we chose to investigate four academic programs, including two that are highly structured and considered challenging to complete within four years and two that are less structured and considered easy to complete within four years. We requested anonymized student data from the Institutional Research, Assessment & Planning Office for true freshmen who began the program in Fall 2017 to test whether these students were able to complete in four years. Knowing that COVID-19 caused a move to online instruction in Spring of 2020, this should only exacerbate issues with finishing in four years.

## Chapter 2: Background

Currently in the field of curricular analytics, studies fall into one of two different categories. One way curricular analytics is being utilized is by universities and professors at their own institution in order to help understand specific situations within the curriculum and try to improve the curriculum over time. Another way curricular analytics is being utilized is by individuals or institutions who have created models or software in order to analyze the curriculum and produce data.

Norris et al. [5] argue for the use of curricular analytics expanded into what they call “action analytics.” In particular institutions should: “Utilize the new generation of open-architecture analytics to enhance access, affordability, and success for learners. . . .Develop new practices/solutions that ensure the alignment of institutional goals, strategies, initiatives, interventions, outcomes, and measures in a variety of ways, including alignment from institutional to college to department to program levels. . . .Develop organizational capacity and change culture to encourage evidence-based behavior and action-focused innovation to improve performance” [5].

Heileman et al. [2] provide suggestions for using curricular analytics to create a framework to measure “the extent to which curricular or pedagogical interventions impact student progression.” Their goal is to motivate discussions with faculty and curriculum committees drawing on actual data presented in a framework, rather than making decisions “with opinion and ill-defined success criteria.”

They develop the framework by considering two components: “Instructional Complexity: the manner in which courses in the curriculum are taught and supported, and Structural

Complexity: the manner in which the curriculum is structured.” They create schematic diagrams for structural complexity and mathematical models for both structural and instructional complexity and use the models to analyze the curriculum of several engineering programs. We will use a similar schematic diagram of the structural complexity of programs in our analysis [2].

Similarly to Heileman et al., Ochoa [6] states that curricula are typically analyzed in a subjective way. He therefore proposes a list of metrics to objectively analyze curricula and validates these metrics through various studies. These metrics are calculated through curriculum interaction data (academic records) and include three types: intrinsic, extrinsic, and interaction [6]. Hickman [3] discusses how the complexity of a curriculum can influence a student’s ability to move through it. He then describes a software created to simulate students moving through curricula and shows a negative correlation between complexity of curriculum and student success.

Other research focuses on actual analysis of data using curricular analytic techniques. For example, Hilliger et al. [4] describe a study they conducted to develop and test a model for analyzing the curriculum through a standard mechanism for determining whether students achieved intended levels of competency. The model automatically pulled performance data for classes in an engineering major from the LMS and with faculty input provided a metric for competency that could then be reviewed and used to make adjustments to the curriculum. Similarly, Salazar-Fernandez et al.[8] examined the educational trajectories (course sequences including failure, withdrawal, and stop-out) for 10,969 students who had a stop-out (i.e., took one or more terms off before returning) using curricular analytics techniques. Their results pointed to ways to intervene when students returned to complete their programs.

The Office of Institutional Research at Sacramento State University [7] determined five bottleneck courses within the Department of Biology, through “course sections offered, enrollment change, overflow of classroom, repeaters, and waitlists.” They then examined the supply versus the increasing demand of the determined classes to see if this was a cause for



the bottlenecks and concluded that this was one of the factors. This article in particular motivated us to consider investigating bottleneck courses.

We will investigate bottleneck courses within four different programs, two highly structured and considered challenging to complete within four years, and two that are less structured and considered easy to complete within four years. We will look at two questions in particular:

- Are “bottleneck” courses – defined as one with three or more other courses directly or indirectly requiring it as a prerequisite – the courses students are withdrawing from or failing the most?
- Are highly structured majors, with more bottleneck courses, causing students to change majors?

## Chapter 3: Academic Programs

To determine the role course sequencing plays in time to degree, the academic advisor team at the university was asked to provide a list of programs they perceived as being challenging to complete in four years and another list of those easy to complete in four years. We decided to investigate four academic programs on the team's recommendation:

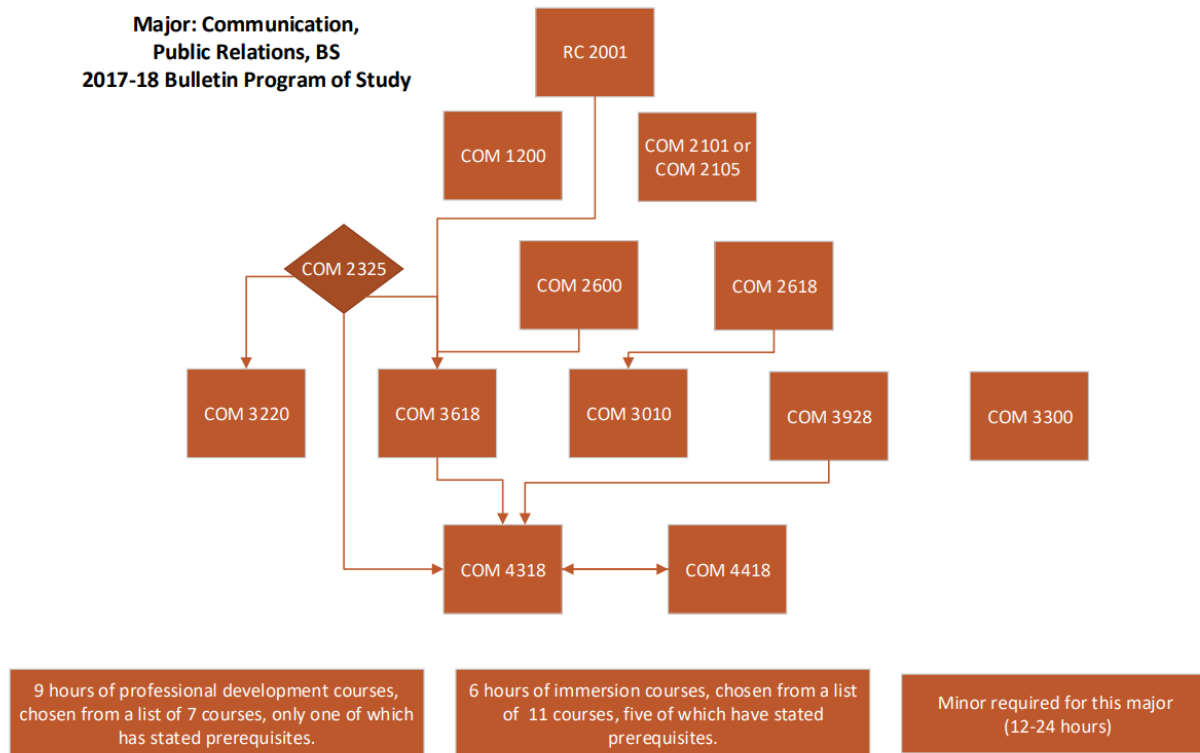
1. Communication, Public Relations, BS, hereafter referred to as Public Relations;
2. Criminal Justice, BSCJ;
3. Interior Design, BS; and
4. Health and Physical Education, K-12, BS, hereafter referred to as Physical Education.

Two of these programs (Interior Design and Physical Education) are considered by the academic advising team to be more "rigid" in structure, including courses with multiple prerequisites building off of each other. As a contrast, the other two programs (Public Relations and Criminal Justice) are considered to be more "flexible," including courses with less prerequisites and a "flat" structure.

Using the official program of study from the 2017-18 undergraduate bulletin, we examined these four academic programs to identify where the potential bottleneck classes appear to be, and if the more structured majors have more bottleneck classes that could be holding students back. Specifically, we defined a bottleneck course to be any class that has three or more classes directly or indirectly requiring it as a prerequisite. Bottlenecks are denoted with diamond symbols in the course flow charts presented in Figures 1, 4, 7, and 9.

# Public relations

Figure 1: The flexible course flow diagram for Public Relations



When analyzing the Public Relations academic program (Figure 1), we only found one potential bottleneck class, Public Relations Principles (COM 2325). Looking at the program, only two classes have more than one prerequisite, both of which require COM 2325. Because of this, the academic program appears relatively flat. The published Four-Year Plan for Public Relations majors provides much more specific advice on a path through the curriculum for students; however, students who deviate from the Four-Year Plan can still complete the program efficiently.

In particular, the program recommends that students on a regular schedule (i.e., starting as freshmen in the Fall semester) complete courses in the order shown in Figure 2.

Figure 2: **Four-Year Plan for Public Relations**

	Fall	Spring
Year 1	COM 1200	COM 2101 or 2105
Year 2	<b>COM 2325</b> ; COM 2618; RC 2001; Professional Development Course 1	COM 2600; COM 3220; COM 3318; Minor Course 1
Year 3	COM 3300; COM 3618; Professional Development Course 2; Minor Course 2	COM 3010; COM 3928; Immersion Course 1; Minor Course 3
Year 4	COM 4318; Professional Development Course 2, Minor Courses 4 and 5	COM 4418; Immersion Course 2; Minor Course 6

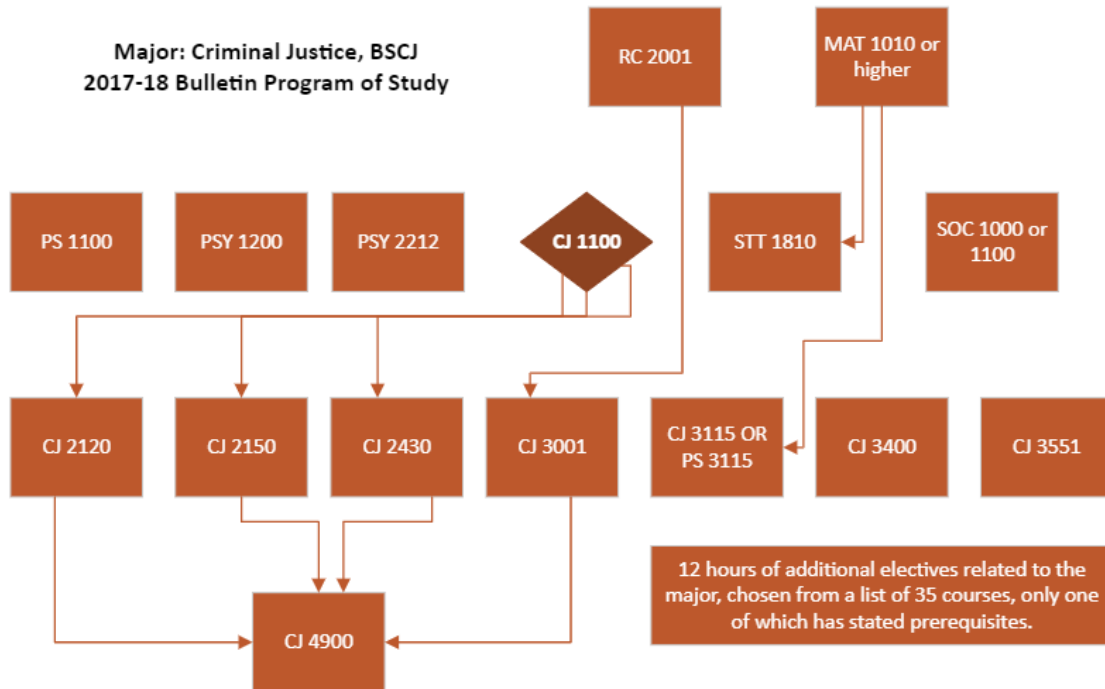
All of the major required courses and most of the immersion and professional development course options have term of offering specified as Fall and Spring, and so COM 2325 could be successfully completed as late as Spring of Year 3, as shown in Figure 3 where “withdrawn/failed” is represented by “**W/F**” and “repeated” is represented by “**R.**”

Figure 3: **Alternate Four-Year Plan for Public Relations, assuming COM 2325 must be repeated**

	Fall	Spring
Year 1	COM 1200	COM 2101 or 2105
Year 2	<b>COM 2325(W/F)</b> ; COM 2618; RC 2001; Professional Development Course 1	COM 2600; COM 3010; COM 3928; Minor Course 1
Year 3	COM 3300; Professional Development Course 2; Minor Course 2	<b>COM 2325(R)</b> ; Immersion Course 1; Minor Courses 3 and 4
Year 4	COM 3220; COM 3618; Professional Development Course 3; Minor Course 5	COM 4318; COM 4418; Immersion Course 2; Minor Course 6

# Criminal justice

Figure 4: The flexible course flow diagram for Criminal Justice



The second “flexible” program we analyzed was Criminal Justice (Figure 4). When looking at this program, we saw only one potential bottleneck class, Introduction to Criminal Justice (CJ 1100). It is notable that every class in this major has only one or no prerequisites, except for the Internship in Criminal Justice (CJ 4900), contributing to the flat nature of the structure. A repeat of the analysis of the Four-Year Plan completed for Public Relations (Figures 2 and 3) shows even more flexibility in Criminal Justice (Figures 5 and 6). All of the major required courses have term of offering specified as Fall and Spring, and so CJ 1100 could be taken as late as Spring of Year 3, as shown in Figure 6.

Figure 5: **Four-Year Plan for Criminal Justice**

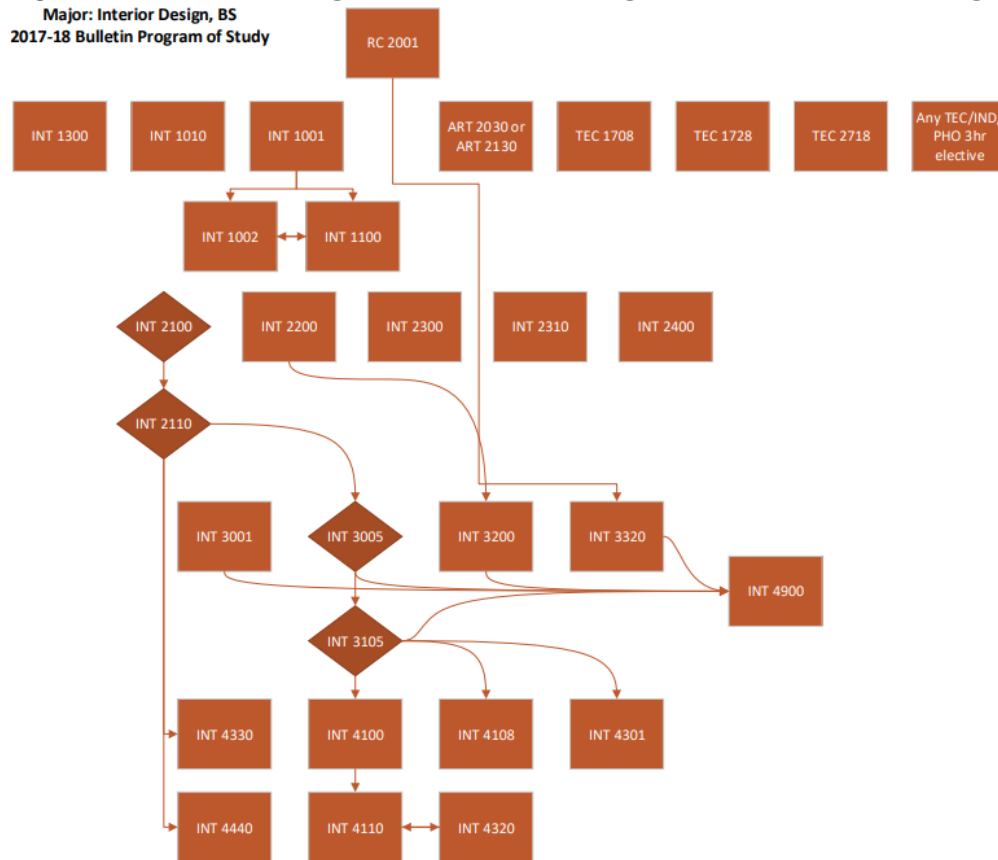
	Fall	Spring
Year 1	<b>CJ 1100</b> , MAT 1010 or higher	STT 1810, PSY 1200, SOC 1000 or SOC 1100, PS 1100
Year 2	PSY 2212, CJ 2120, Major Elective Course 1	CJ 2150, CJ 2430, RC 2001
Year 3	CJ/PS 3115, CJ 3001, CJ 2400, Major Elective Course 2	CJ 3551, Major Elective Course 3
Year 4	Major Elective Course 4	CJ 4900

Figure 6: **Alternate Four-Year Plan for Criminal Justice, Assuming CJ 1100 Must be Repeated**

	Fall	Spring
Year 1	<b>CJ 1100(W/F)</b> ; MAT 1010 or higher	STT 1810; PSY 1200; SOC 1000 or 1100; PS 1100
Year 2	PSY 2212; CJ 3400; Major Elective Course 1	RC 2001; CJ 3551
Year 3	CJ/PS 3115; CJ 3001; Major Elective Course 2	<b>CJ 1100(R)</b> ; Major Elective Course 3; Major Elective Course 4
Year 4	CJ 2120; CJ 2150; CJ 2430	CJ 4900

## Interior design

Figure 7: The more rigid course flow diagram for Interior Design



When analyzing the Interior Design program (Figure 7), we noted four potential bottleneck classes. One of the more unique parts of this academic program's structure is the list of classes that need to be taken in sequential order. A chain of six classes need to be taken that each require the previous class as a prerequisite and are only offered in the Fall semester or in the Spring semester. This means if a student were to miss a required class in the chain, they would need to wait a full year to take it again, and to take any of the following classes. This chain of classes would take at a minimum three years to complete, which makes it difficult for any incoming transfer students to complete the major.

In contrast to Public Relations and Criminal Justice, the Interior Design program is much less flexible; the Four-Year Plan must be followed as presented due to the prerequisite

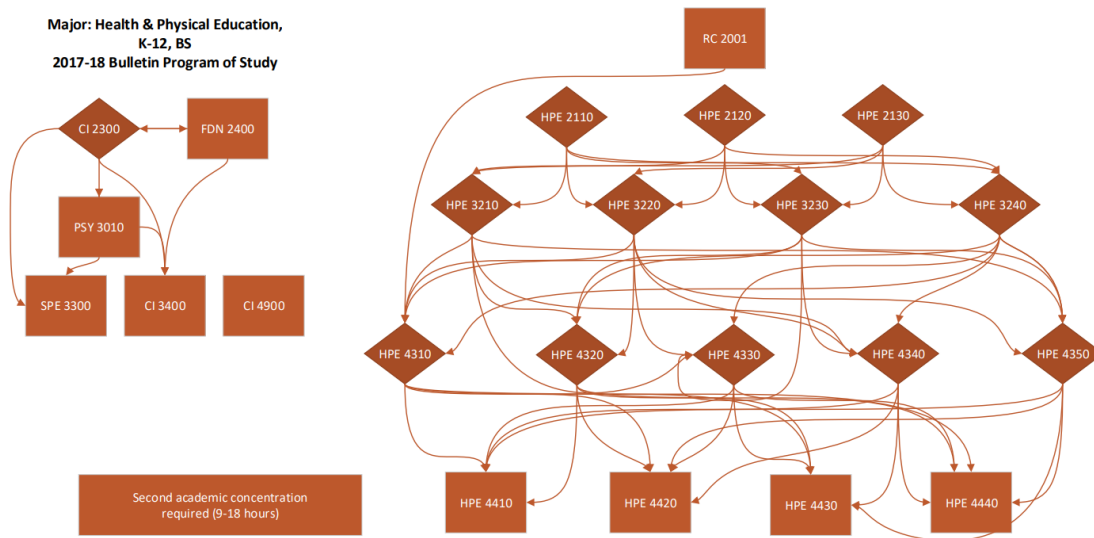
structure. For example the last bottleneck, Interior Design Studio V (INT 3105), still has three more classes requiring it as a prerequisite all needing to be taken in sequential order. Because each of the bottleneck courses are only offered in either the Fall or the Spring, they would need to be taken no later than the semester designated in the Four-Year Plan provided to finish within four years.

Figure 8: **Four-Year Plan for Interior Design**

	Fall	Spring	Summer
Year 1	INT 1300, INT 1001, IND 1010	INT 1002, INT 1100, ART 2030 or ART 2130	
Year 2	TEC 1708, TEC 1728, <b>INT 2100</b> , INT 2300, INT 2400, RC 2001	<b>INT 2110</b> , INT 2200, INT 2310, TEC 2718	
Year 3	INT 3001, <b>INT 3005</b> , INT 3200, TEC/GRA/IND/PHO Elective	<b>INT 3105</b> , INT 3320, INT 4330	INT 4900
Year 4	INT 4100, INT 4108, INT 4301, INT 4400	INT 4110, INT 4320	

## Physical education

Figure 9: **The more rigid course flow diagram for Physical Education**





When analyzing the second “inflexible” academic program, Health and Physical Education (Figure 9), we noted 13 classes as potential bottlenecks. This major is designed so every set of classes is a prerequisite for the next, in a hierarchical pattern. While all of these bottleneck classes are offered both Fall and Spring semesters, this hierarchical pattern makes it difficult to take the next set of classes. If a student were to miss one of these courses, there would be four or five courses they would not be able to take the following semester. The chain of prerequisite courses is four semesters long, so there is little room for students to fail a class or for a transfer student to come into the program later on.

This inflexibility is represented in the Four-Year Plan as well (Figure 10); just as with Interior Design, given the structure of the Physical Education program and the way the prerequisites are set up, a student is not able to take a set of classes until the previous ones are complete. Due to this, it would be difficult for students to take classes later than the Four-Year Plan recommends or else they would risk not graduating within four years.

Figure 10: **Four-Year Plan for Physical Education**

	Fall	Spring
Year 1	<b>HPE 2110</b> , BIO/CHE/PHY course 1	<b>HPE 2120</b> , BIO/CHE/PHY course 2
Year 2	<b>HPE 2130</b> , <b>CI 2300</b> , RC 2001	<b>HPE 3210</b> , <b>HPE 3220</b> , <b>HPE 3230</b> , <b>HPE 3240</b> , PSY 3010
Year 3	<b>HPE 4310</b> , <b>HPE 4320</b> , <b>HPE 4330</b> , <b>HPE 4340</b> , <b>HPE 4350</b> , FDN 2400	HPE 4410, HPE 4420, CI 3400
Year 4	HPE 4430, HPE 4440, SPE 3300	CI 4900

After examining these four programs, we can see that the most flexible, with only one bottleneck class and few prerequisites required throughout the degree, is Criminal Justice. On the other hand, the least flexible, with 13 bottleneck courses and many prerequisites required, is Health & Physical Education. After determining the bottleneck courses within these programs, we can now categorize the data provided to show if these courses are the ones that students are failing and withdrawing from most often, and if the highly structured

programs have a higher rate of students switching majors.

## Chapter 4: Description of Data

To further investigate the notion that students have more difficulty completing rigid majors in four years due to bottleneck courses and the overall structure of the major, data was requested from the Institutional Research Office for all students who began as freshman (perhaps with AP credit or other transfer of under 15 hours) in Fall 2017 in one of the four majors under discussion. The data set was provided as an Excel spreadsheet where each row represented one student's attempt at one course. The data set included 5831 rows of information for 145 students (Figure 11).

Each row contained the following fields:

- Column A: Unique anonymized identification number for the student
- Columns B and C: Entering major code and description
- Columns D and E: Graduation term and description
- Columns F and G: Graduation major code and description
- Column H: Note on if graduating major was the same as entering major or what it changed to
- Columns I and J: Term course and description
- Columns K, L, and M: Course subject code, number, and title
- Column N: Course grade status (Pass/Fail/Withdraw)

Figure 11: Summary of data provided

Major	# of Students	# of Students Graduated (any major)	# of Students Graduating with same Major	Average Length of time to Graduation	Avg. Length of time to Graduation (Only same major)	Number of students who switched major & graduated
Communication, Public Relations, BS	24	17 (70.83%)	10 (41.67%)	3.85	3.8	7
Criminal Justice, BSCJ	76	58 (76.31%)	40 (52.63%)	4.11	4.06	18
Interior Design, BS	35	31 (88%)	21 (60%)	4.01	4.02	10
Health and Physical Education, K-12, BS	10	7 (70%)	7 (70%)	4	4	0

These data allowed us to identify students who: failed, withdrew from or repeated classes; changed majors; did not graduate. For example, Figure 12 provides an excerpt from the dataset showing student 36, a Criminal Justice major who graduated in Spring 2021 who withdrew from CJ 2150 in Fall 2018 and retook the course in Spring 2019. Figure 13 shows a row for a student who switched majors: Student 17 began as a Public Relations major and later switched to a Finance & Banking major.

Figure 12: Student who withdrew from and later retook the same course

Unique_Id	Entering Major Code	Entering Major Description	Graduation Term	Graduation Term Description	Graduation Major Code	Graduation Major Description	Graduation Note	Term Course	Term Course Description	Course Subject Code	Course Number	Course Title	Course Grade Status
36	220A	Criminal Justice	202110	Spring 2021	220A	Criminal Justice	same major	201840	Fall 2018	CJ	2150	THE COURT SYSTEM	Withdraw
36	220A	Criminal Justice	202110	Spring 2021	220A	Criminal Justice	same major	201910	Spring 2019	CJ	2150	THE COURT SYSTEM	Pass

Figure 13: Student who graduated with a different major

Unique_Id	Entering Major Code	Entering Major Description	Graduation Term	Graduation Term Description	Graduation Major Code	Graduation Major Description	Graduation Note	Term Course	Term Course Description	Course Subject Code	Course Number	Course Title	Course Grade Status
17	521A	Public Relations	202140	Fall 2021	326A	and Insurance	different	201940	Fall 2019	ECO	2100	STATISTICS I	Pass

## Chapter 5: Analysis of Data

### **Are the “bottleneck” courses we identified what students are withdrawing from and failing most?**

To investigate this question, we filtered the data by course grade status to only show courses that were withdrawn and failed. We organized this subset by course title and determined which courses appeared most and noted courses that appeared 5 or more times. After examining this list, we compared the most failed/withdrawn courses to our determined bottleneck courses. This allowed us to see if there was any overlap, and if these were keeping students from progressing through their curriculum successfully and timely.

According to the data set, this does not seem to be the case. While we originally hypothesized that the bottleneck classes within the academic programs would be the classes most students would be failing and withdrawing from, the data shows this is true for other classes instead.

Hypothesized classes to be failed/withdrawn most (bottlenecks):

- Public Relations: COM 2325 (never occurred)
- Criminal Justice: CJ 1100 (only occurred once)
- Interior Design:
  - INT 2100 (only occurred once)
  - INT 2110, 3005, 3105 (never occurred)
- Physical Education:

- HPE 2110, 2120, 2130, 3210, 3220, 3230, 3240, 4310, 4320, 4330, 4340, 4350 (never occurred)
- CI 2300 (never occurred)

The classes most failed/withdrawn according to the dataset in particular (where 5 or more students failed or withdrew) were MAT 1010 (7), RC 2001(5), HIS 1200 (5), ACC 2100 (6), and INT 3545/47 (8).

- MAT 1010: This course is a prerequisite for Criminal Justice and is also a quantitative literacy option within the general education program taken by many students in these majors.
- RC 2001: This course is required for all students within the university as part of general education.
- INT 3545/47: This course is an elective within the Interior Design program.
- HIS 1200: This course is a commonly selected general education course option.
- ACC 2100: This course is required within the General Business minor and many students in Public Relations and Criminal Justice complete this minor.

To further investigate courses where students encountered difficulties, we counted the number of instances of failures and withdrawals by prefix. Figure 14 lists all prefixes with 5 or more instances. Many of the courses are components of the general education program taken by all students who enter as freshmen or minors that are typically taken by students in communication and criminal justice.

Figure 14: Prefixes and count of withdrawn/failed instances

Prefix	Count of W/F
COM	24
PSY	22
SOC	22
HIS	19
CJ	18
INT	13
FIN	12
PE	12
ACC	11
MAT	11
PS	8
RC	8
ART	6
CHE	6
ENG	6
HPE	6
MUS	6
PHO	5

### **Are highly structured academic programs with more “bottleneck” courses causing students to switch majors?**

While acknowledging that we did not have a similar number of students from each of the four academic programs, we can still look within the dataset to see who changed majors (Figure 11). We can see that out of the 17 students to come in as a Public Relations major and successfully graduate, 7 graduated with a different major (41.17%). The majors these students switched over to were:

- Communication Studies, BS (2)
- Communication, Electronic Media/Broadcasting, BS
- Apparel Design and Merchandising, BS
- Finance and Banking, BSBA
- Political Science, BS
- Recreation Management, BS

We can see that out of the 7 students who changed majors, 3 changed within the same academic department.

Criminal Justice, our largest subset of students, had 18 students change majors out of the 58 students who successfully graduated (31.03%). The majors these students switched over to were:

- Communication Studies, BS (2)
- Political Science, BS (2)
- Accounting, BSBA
- Building Sciences, BS
- Communication, Public Relations, BS
- Communication, Electronic Media/Broadcasting, BS
- Computer Information Systems, BSBA
- Dance Studies, BA
- English, BA
- Exercise Science, BS
- Finance and Banking, BSBA
- History, BA
- Languages, Literature, and Culture, BS
- Marketing, BSBA
- Psychology, BS
- Social Work, BSW

Out of these 18 students who changed majors, 2 changed within the same academic department.

When looking at the highly structured academic programs, out of the 31 students who



began as an Interior Design major and graduated, 10 of the students graduated with a different major (32.25%). The majors these students switched to were:

- Social Work, BSW (2)
- Building Sciences, BS
- Communication, Public Relations, BS
- Exercise Science, BS
- Marketing, BSBA
- Psychology, BS
- Religious Studies, BA

Out of these 10 students, none of the students switched to a major within the same academic department.

Although in our dataset we did not have any students who began as a Physical Education major to change majors, we know this can not be representative of every student to come into the program. We recognize that there are only 10 students represented here and therefore can not give an accurate representation of the entire major.

According to our data, we do not see a notable difference between the percentage of students who change majors from less structured academic programs as compared to highly structured academic programs. We do see a higher percentage of students who, when changing their major, change to a major that is still within the same academic program. However, we cannot conclusively say that the structure of the academic program is causing students to change majors.

## Chapter 6: Conclusion

### Limitations

There are a number of limitations to this study, several of which provide information as to paths for further investigations. The data provided only allowed us to analyze students who began within the academic programs we are studying. The data currently shows students who begin and finish in the program, along with students who begin in the program but switch to another program along the way. If data were available for students who switched into these programs, we could analyze the effect of the indicated bottleneck classes on time to graduation and how easy it is for students who entered the major late to graduate on time.

Another limitation in the data provided is there were only ten Health and Physical Education majors. Among these ten students, seven students graduated and none switched their major. We know this is not representative of every student that enters as a Physical Education major, and therefore know that our analysis of the Physical Education major and the bottlenecks within it are limited. This smaller number of students may be due to several issues, one of which could be the rigidity of the curriculum.

To include students graduating within four or five years, our data focuses on true freshmen beginning in Fall 2017. Due to this, our data also includes the time period in which course formats were altered due to COVID-19. We initially anticipated that COVID-19 would negatively affect time to degree, but there is no evidence of this occurring in the data. We did not want to go farther back than 2017 to retrieve data since the curriculum has changed

and any conclusions we could draw might not be relevant for current students and the existing curriculum.

## **Future Investigations**

Moving forward, we would definitely like to analyze if the time to graduation is affected by the structure of the degree when a student graduates in a different academic program than they entered. Specifically looking at the published Four-Year plans, the structure of the more rigid programs appears to keep students who are switching majors or transferring in from finishing within four years. It would be interesting to have data on students who began as one major (could be any major), but later switched into either Interior Design or Physical Education and how long it took these students to graduate compared to students who began as one major but later switched into either Public Relations or Criminal Justice.

Another factor we would like to analyze is if the course availability of these determined bottleneck classes has an impact on time to graduation. After concluding that these bottleneck classes are not the classes most withdrawn/failed, but seeing they are still critical to a student's success in moving through the curriculum, it would be interesting to see what affect the course availability has on time to degree completion and if some of these bottleneck classes should be offered more often to help students graduate on time.

Additionally, it would be interesting to map out the courses for each student in the major who changed or did not graduate to see how closely they stuck to the 4 year plans.

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## Vita

Jayne Hollar graduated from Appalachian State University with honors in mathematics in Spring 2023. She plans attend graduate school for analytics and then later begin a career in data analysis.