Study of Flowchart Slippage

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Introduction

How well do students follow faculty-defined flowcharts? Is student progress in lock step with flowcharts? How much does progress vary by major, or for part time students? How does advanced placement credit impact progress on a flowchart?

We refer to the difference between ideal progress suggested by the flowchart and actual progress as "slippage." The general idea that student progress slips compared to a flowchart is not unexpected. However, the degree to which slippage accumulates along prerequisite chains and the opportunities to reduce it were surprising. A regression analysis was used to model slippage, with the goal of identifying dependent variables that are correlated to changes in slippage along prerequisite chains. In this initial study, we analyzed the 2015-2019 cohort of Computer Engineering students at Cal Poly in San Luis Obispo, California.

This study builds on concepts from prior work on curriculum complexity metrics [1] [2]. We extend the prior work by including comparisons with actual student data, and we use regression analysis to verify the existence of trends and the correlation to explanatory variables including the number of prerequisites and mean course grades. Results are consistent with assumptions made in prior work by [1] [2] and with aspects of their complexity model.

A tenet of this work is that the root causes for flowchart slippage are primarily systemic in nature and not due to a lack of interest or ability on part of the student. Examples of these systemic issues include work commitments, family care, and part-time enrollment. Additional factors include change of major, internships and study abroad. These issues are exacerbated by curricular complexity. From this backdrop, we pose the following research questions:

1. Are slippage patterns discernible in sequences of courses?
2. Is slippage correlated to curriculum complexity metrics and academic data?
3. Under what conditions does slippage tend to lessen?

Results indicated correlation values as high as 0.67 between slippage and our dependent variables. Results also demonstrated instances where flowchart slippage was reduced! Our comparison of actual student progress versus the flowchart provided a means to confirm assumptions made by others in prior work.

Inspiration from prior studies

Prior effort by Heilman [1] and Grote [2] examined progress to degree analytically and created a framework for comparing different curricula. Their approach yielded a complexity metric that can be used for comparisons. The structural complexity of a curriculum was defined by Heilman [1] using two primary quantities: a delay factor and a blocking factor. The delay factor of a course is the length of the longest prerequisite chain that includes the course. The sum of delay factors for all courses then provides a metric for the curriculum. The blocking factor for a course is the count of the number of courses reached by follow-on prerequisites. This is also summed for all courses in the curriculum. Grote [2] demonstrated the validity of curricular complexity metrics by examining the correlation to actual graduation rates. Table 1 compares the use and effect of quantities defined in prior work [1] [2] to the slippage analysis.

Table 1: Comparison of quantities defined in prior studies to the slippage analysis.

Quantity	Prior work	Slippage analysis
Overall complexity metric	Higher complexity metric correlated to lower graduation rates.	Greater slippage results in delayed progress to degree.
Delay factor	Courses on long prerequisite chains produce larger contributions to complexity metric, reducing graduation rates.	Slippage tends to increase along prerequisite chains, delaying progress. Slippage is the outcome variable for the regression analysis.
Blocking factor	Courses with more prerequisites produce larger contributions to the complexity metric, reducing graduation rates.	The number of prerequisites is an explanatory variable for the regression analysis.
Pass rates	Lower pass rates for courses reduce graduation rates.	Mean grades are used as an explanatory variable for the regression analysis.

Both the slippage analysis and prior studies include factors such as prerequisites, the length of course sequences, and course grades. Other similarities involve the nature of the cohort. Heilman assumed that no students dropped out of their program. For slippage, only students who graduated with no changes in major were included. Also, both studies involved major and support courses only, hence, no general education requirements or electives were included. To simplify the analysis, no lab courses were included as they are corequisites.

An advantage of the slippage analysis compared to prior work is that it can capture the effect of many confounding factors that impact student progress. While these are not explicit variables in the analysis, the following factors are reflected in the archival student data. In the following list, factors 1-5 tend to increase slippage, factor 6 tends to reduce it.

1. Class enrollment limits
2. Course availability term-by-term
3. Maximum number of units a student might reasonably attempt in a term
4. Part-time enrollment
5. Participation in internship programs
6. Summer catch-up courses

Archival data

Slippage analysis is cohort-based, including first-time freshmen students in a specified major and year of admission. Due to the focus on degree progress, these cohorts are limited to students who graduated without ever changing majors. Admittedly, these conditions skew results favorably. However, many confounding factors can impact students who do not graduate or who change majors. And these confounding factors may not be related to complexity metrics. Hence, the use of a more narrowly defined cohort. This study included First-Time First Year (FTFY) Computer Engineering students in the 2015 cohort. Archival data for this study was part of a larger data set established as part of a project funded by the National Science Foundation. Use of data from this source was unfortunately limited as 2015 was the last cohort available prior to the COVID pandemic. It was also the last cohort prior to significant changes in the curriculum. A more recent award is providing new opportunities to extend this work with more new cohorts and varied student populations.

Regression analysis of slippage

A regression analysis was used to predict changes in slippage at the course level. Explanatory variables for the regression analysis were based on similar quantities used in prior studies. The regression outcome variable was the slippage of a particular course. Explanatory variables for each course in the regression were:

1. Slippage of the prior course (using the closest prerequisite as the prior course)
2. Mean course grade (computed for each course individually, for students in the given cohort and for A-F grades only)
3. Number of prerequisites for the course
4. Course flexibility (fraction of the cohort not taking the course)

A correlation of 0.67 was found to exist between the predicted change in slippage and these explanatory variables, as found via the R value of the regression analysis. The regression was not statistically significant. However, this may be in part due to a low number of courses, $N = 13$. Courses were restricted to those with both prior slippage and a nonzero number of prerequisites.

Graphical depiction of results

In preface, note that this effort is not intended to publicly shame faculty members or individual departments. Thus, the course prefix and course numbers seen in Figure 1 have been anonymized.

Each course is shown with a blue box. Slippage appears as a red C-shape on the left side of the blue course boxes, with a width determined by the mean slippage. Green rectangles are associated with negative slippage, having a mean term of enrollment that is advanced relative to the ideal flowchart. Black rectangles indicate courses that may be taken anytime during a span of terms. Lines between boxes indicate prerequisites. Blue lines connect the closest prerequisite courses and are designated as critical prerequisites.

Values for the explanatory variables are shown for each course as bar graphs within the blue boxes. For each variable, wider bars indicate a greater potential to increase slippage.

1. (Red bar) Slippage of the critical prerequisite, the prior course closest in time.
2. (Purple bar) Student grades for the cohort. Shown as a complement of the mean grade.
3. (Green bar) Number of prerequisites for the course.
4. (Cyan bar) Course inflexibility. Shown as the fraction of the cohort taking the course.

Grades are associated with students' first attempt at taking a course. Mean grades were computed for this specific cohort. The purple bar graphs are displayed in a complementary manner, drawn wider for lower mean grades. The last bar is related to the degree of inflexibility associated with the course. This refers to the number of students in the cohort who did not enroll in the given course, thanks to alternative courses that satisfy the requirement.

Interpretation of results

Accumulation of slippage. See Figure 1. Note the increase in slippage (red) along the course sequence that begins with courses E3 and S6, and includes E5, E6 and C6. These courses have lower grades, more prerequisites and low flexibility (as no other courses satisfy these requirements). This sequence of courses demonstrates the accumulation of slippage along a prerequisite chain.

Reduction in slippage. Also in Figure 1, note the improvement in flexibility, better grades and fewer prerequisites for courses A1 and A2, and the associated dramatic reduction in slippage of courses A3 and A4. Flexibility in A1 and A2 is thanks to alternate courses that satify these requirements. Approximately 16% of the cohort took the alternate path. Reduced slippage via flexibility is an assumption made by Heilman [1]. These results are consistent with Heilman's assumption.

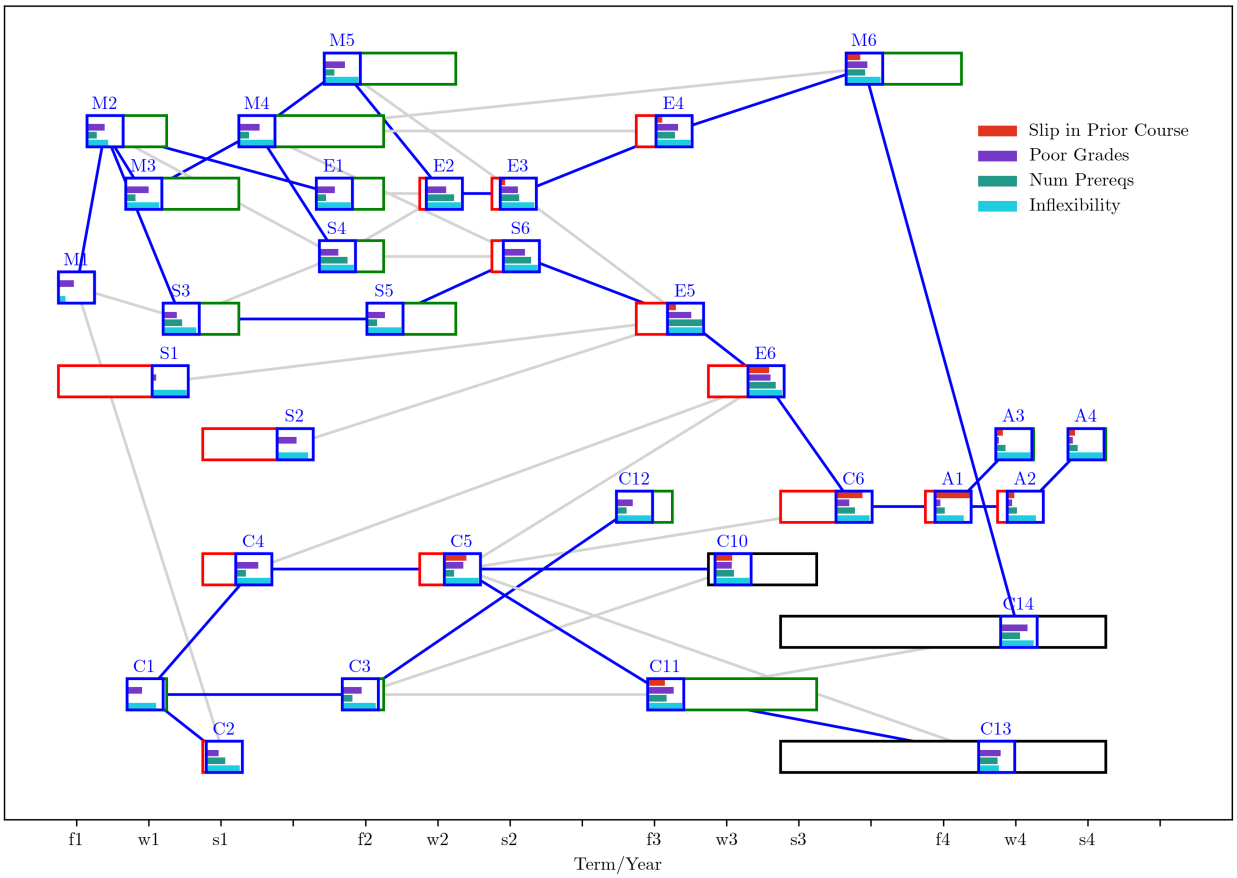

Figure 1: Results of the slippage analysis associated with required courses. An example of the accumulation of slippage (red) may be seen along the course sequence that ends with C6. And, a dramatic reduction in slip occurs thanks to courses A1-A2. This is in part due to alternative courses that may be taken to meet these requirements. Many courses in the upper left were taken early, relative to the flowchart. This corresponds to a negative amount of slippage (green). Early enrollment was thanks to advanced placement credit, primarily in M1 and M2.

Avoiding slippage. An early portion of the curriculum appears in the upper left corner of Figure 1, and slippage in this section is favorably impacted by advanced placement credit. The AP credit allowed students to enroll in courses earlier than designated on the flowchart, hence the green extensions to the blue course boxes. Only 25% of the cohort enrolled in course M1, and just 64% in M2. Most others were 100% enrolled, except for S3 and M3 which were above 95%. Hence, it appears that the benefit of only a small number of advanced placement courses can have a much broader impact and avoid the accumulation of slippage (through E2 and S6 in this case).

Faculty stakeholders and impact

Authors include faculty members who are part of a grant funded by the National Science Foundation to re-imagine the Computer Engineering department (RED #nnnnnn). And coincidentally, the university is also implementing a major curricular overhaul associated with a quarter-to-semester conversion. These two efforts are opportunities for significant curriculum revision. Unfortunately, this slippage analysis did not preceded these revision efforts. Nevertheless, a slippage analysis may prove useful for comparison purposes. Also, a co-author of this study is the scheduler for the Computer Engineering and the Computer Science Departments. These results provide insights that may benefit scheduling and student advising.

Conclusions and summary

This study has confirmed that slippage clearly accumulates and that it can be reduced or avoided in some cases, for example via alternate courses and AP credit. Results suggest that more than just course grades impact slippage. This study also helps validate some assumptions in prior work [1] [2]. Also, relative to these prior efforts, slippage analysis can provide information on course enrollment delays in terms of quarters or semesters. Prior approaches also support "what if" scenarios for curricular revision, but slippage analysis cannot as it is based on posterior enrollment data.

Results also suggest that it is possible to reduce slippage. This could be helpful when redesigning a curriculum. For example, introducing course(s) to reduce slippage following some "harder" courses to help quash slippage, rather than allowing a trend to accumulate. A simple example might be to include alternate courses to satisfy a requirement, but that may have more relaxed prerequisites.

This study also brings new questions to light. For example, what fraction of students taking longer than 4 years to graduate also changed majors? How many are part-time? How much do these results vary by major and by cohort year?

Transfer students are another important consideration. Internal studies have shown that incoming transfer students (from over 110 community colleges in California) enter the curriculum at varying points. Based on the apparent effect of advanced placement courses, it seems that FTFY students also have varied progress as they enter courses alongside transfers: E2, E3, S6 (many transfers need to take these second year courses). Thus, it appears that both transfers and FTFY students each have some level of variability in their degree progress as they begin common coursework. This is of interest because prior studies that compared transfer to FTFY students at

Cal Poly [3] demonstrated the effect of lower grades known as “transfer shock” [4]. These results suggest that the variability in degree progress (i.e. slippage) is a common effect for both transfer and FTFY student populations. This supports the idea that transfer shock is due to other factors such as the loss of academic and social networks [5] as opposed to when and which courses are taken.

Acknowledgements and qualifiers

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Every effort has been made to provide accurate information in this study. However, this report is not an official publication of the Cal Poly Office of Institutional Research. So, rather than serve as an official report on student progress, the goal here is to identify some best practices and to suggest opportunities for improvement.

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