DISCOVERING PATHWAYS TO SUCCESS IN STEM DISCIPLINES

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Abstract

The fields of Science, Technology, Engineering and Mathematics (STEM) are viewed as essential to the economic competitiveness of the United States on the global stage (US Department of Education). While vital to the nation's economic prosperity, enrollment in STEM fields at the college/university level has remained relatively stable, despite millions of dollars expended to improve STEM education and retention. Most extant research focuses on innovations within classroom settings that can improve learning outcomes for students pursuing STEM majors. We believe additional research is needed examining how the sequencing of courses taken by students can help or hinder their progress toward the successful completion of a STEM degree. In this first phase of our research, we used quantitative analytics to identify the power impact of specific courses and the risk of dropping out for students majoring in Mathematics. This pilot research project will serve as the foundation for a larger research project, where our analytical model will be tested using students enrolled in all STEM disciplines at WKU and at other colleges/universities.

Keywords: STEM, Survival Analysis, Predictive Model, Course Sequencing, Data Mining.

Background

The United States was the leader in scientific discovery, medical research, and technological innovation during the later half of the twentieth century. However, this stature has waned over the last decade as other countries increased human capital investments in software and computer engineering, mathematics, medicine, and the natural sciences. Only 16% of undergraduates complete degrees in the natural sciences or engineering in the United States today [1]. This figure is small in comparison to the 47% of undergraduates in China, 38% in South Korea, and 28% in France [1].

With significant funding from the National Science Foundation (NSF), researchers have identified the instructional and pedagogical classroom practices most likely to promote student success within STEM courses and majors. NSF grants have been awarded to colleges and universities to fund the implementation of these best practices and to evaluate their effectiveness over time. Specifically, NSF's Transforming Undergraduate Education in Science, Technology, Engineering, and Mathematics (TUES) was created to fund "projects that have the potential to transform undergraduate STEM education . . . by bringing about widespread adoption of classroom practices that embody understanding of how students learn most effectively" [2] .This TUES initiative has generated an extensive body of literature which shows traditional methods of classroom instruction, with a focus on formal lectures, labs and periodic examinations, result in weaker student learning outcomes compared to classroom settings that encourage faculty-student collaboration, group work, and active learning opportunities. As DeHaan notes in [3], "instructional strategies that encourage undergraduates to become actively engaged in their own learning can produce levels of understanding, retention and transfer of knowledge that are greater than those resulting from traditional lecture/lab classes" within STEM courses. There seems to be conclusive evidence that "active and collaborative instructional strategies are more effective than traditional lecture and discussion across most if not all dimensions of student learning" [4].

These curricula and pedagogical changes encourage experiential, hands-on, and group learning as a means of improving the acquisition, retention, and application of knowledge [5]. STEM courses that increase interaction between faculty members and students, incorporate research, employ active learning strategies designed to get students using technology and equipment, use of collaborative group projects, and apply acquired knowledge to real world local and global problems/issues appear to yield the strongest learning outcomes [5, 6]. Such findings have influenced colleges and universities to make changes in their curricula and to encourage and persuade faculty members to adopt a diverse set of instructional techniques. Courses such as calculus, which represents a gateway course to future STEM courses and majors, have been restructured to encourage more interaction between faculty and students coupled with active and collaborative learning environments.

Prior research has focused almost exclusively on the importance of these instructional and pedagogical changes. Their positive impact on student learning outcomes has created the perception that student retention and success within STEM can easily be extended if more faculty members adopt these instructional techniques [4]. While there may be some merit to this argument, it is unlikely that every STEM faculty member can be encouraged, persuaded, and/or forced to adopt these best practices. Due to institutional inertia and academic freedom, some professors and departments may refuse to participate in these new strategies. Moreover, faculty members who seek out instructional techniques that reflect the best practices of instruction see their teaching as important, and therefore, they are the ones most likely to employ some aspects of these very techniques, even if in limited form. Given these realities, we believe future research should identify institutional factors outside of classroom instruction that promote student retention and success in STEM courses and disciplines.

Research Tasks

This research project is divided into several stages. In Stage 1, we used data from WKU's IR office to define which courses have the most impact on dropping out from a Math major and the risk of dropping out at specific time for freshman who declared math as their major at WKU.

Data Description

- The data set for MATH728 Major includes 272 observations. Each observation is *one* student, distinguished by a unique student ID. This ID is used for identification across the data.
- Each observation consisted students' first term, their majors, student's type (Transfer, Freshman, sophomore, junior, senior…), information from high school (High school GPA, SAT scores,) race, gender, and current status.
- Student and score data are extracted for entering (major) cohorts from 2001 to 2007.

Outcome summary

Variable	Median	Mean	Mode	Range
HS_GPA	3.760	3.576	4.000	2.650
HI_ACT_COMP	24.000	23.806	20.000	21.000

Table 1: Descriptive Stat

STATUS	Frequency	Percent	Cumulative Frequency	Cumulative Percent
DROPPED OUT	88	32.35	88	32.35
ENROLLED-MATH	2	0.74	90	33.09
ENROLLED-OTHER	2	0.74	92	33.82
GRAD-MATH	92	33.82	184	67.65
GRAD-OTHER	88	32.35	272	100.00

Table 2: Sample Outcome

- Of the students observed, we found that 33.82% of them graduated with the Math degree, 32.35% of them decided to change their major and graduated with other degrees, 32.35% of those students dropped out, 2% still enrolled currently in Math major and the other 2% enrolled in other majors.

Statistics by Genders and Races

- Gender: Student body consists of 135 females and 137 males. There is NO correlation between gender and graduation rate (P-value of Chi-Squares test is 0. 2273).
- Race: Student body consists of 241 non-Hispanic White (88.6%) and 31 for the others (11.4%).
  There is correlation between races and the rate of successful students in MATH major. (P-value of Chi-Squares test is 0.0251).
  (*) This test we only look at the difference between students who are successful in the major *(graduate within 8 years)* and students who dropped out or changed the major. Currently Enrolled students in Math are not included.

Statistic	DF	Value	Prob
Chi-Square	1	5.0204	**0.0251**
Likelihood Ratio Chi-Square	1	5.6101	0.0179
Continuity Adj. Chi-Square	1	4.1585	0.0414
Mantel-Haenszel Chi-Square	1	5.0018	0.0253
Phi Coefficient		0.1364	
Contingency Coefficient		0.1351	
Cramer's V		0.1364	

Table 3: Statistics for Table of GradM_or_Drop by white

Building a Model (Regression Model)

- Dependent variable: Math Grad students
- Independent Variables: Hi-school GPA, ACT, Race, genders.

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	-4.7326	1.4040	11.3632	0.0007
HS_GPA	1	0.3524	0.4397	0.6424	0.4229
HI_ACT_COMP	1	0.0886	0.0428	4.2833	**0.0385**
white	1	0.5478	0.6880	0.6341	0.4259
female	1	0.1982	0.3142	0.3979	0.5282

Table 4: Analysis of Maximum Likelihood Estimates

Among those variables, only Hi_ACT_COMP has predictive power on whether a student would succeed in Math major. The positive correlation between Grad in Math and Hi_ACT_COMP means if the higher ACT composite score ACT score, the more likely that student would graduate with MATH major.

Even when the chi-square test of GradM_or_Drop tells us that Race has correlation with the rate of successful students in MATH major, however, when we run the regression for event Grad_MATH, race no longer has predict power on whether student would graduate in MATH.

Analysis of Maximum Likelihood Estimates

Parameter	**STATUS**	**DF**	**Estimate**	**Standard Error**	**Wald Chi-Square**	**Pr > ChiSq**
HS_GPA	DROPPED OUT	1	**-1.2085**	0.4212	8.2324	**0.0041**
	ENROLLED-MATH	1	1.0206	2.4602	0.1721	0.6783
	ENROLLED-OTHER	1	**-2.1434**	0.9352	5.2526	**0.0219**
	GRAD-MATH	1	0.3659	0.4881	0.5619	0.4535
white	DROPPED OUT	1	-1.0730	0.6260	2.9384	0.0865
	ENROLLED-MATH	1	8.7346	248.2	0.0012	0.9719
	ENROLLED-OTHER	1	9.4711	203.7	0.0022	0.9629
	GRAD-MATH	1	-0.1058	0.7502	0.0199	0.8879
female	DROPPED OUT	1	0.4791	0.3629	1.7431	0.1867
	ENROLLED-MATH	1	-10.4939	146.4	0.0051	0.9429
	ENROLLED-OTHER	1	0.6053	1.4703	0.1695	0.6805
	GRAD-MATH	1	0.2021	0.3425	0.3480	0.5552

Table 5: Analysis of Maximum Likelihood Estimates

We examined if variables such as High school GPA, high school SAT, Ethnicity, and gender have correlation with whether a student would succeed with Math major. “Success” in this case is defined as students who graduate with a math degree *within 8 years.*

The above table shows the coefficients (labeled as Estimate), their standard errors (error), the Wald Chi-Square statistic, and associated p-values.

By looking at the multinomial test:

- Ethnicity and genders have no effect on student’s success in Math major
- High school GPA has no effect on whether a student would graduate or enroll in math. However, it has predict power on whether a student would drop out or enroll in other major. The negative correlation between HS_GPA and DROPPED OUT indicate that if a high school GPA increase one unit, the probability of the event “DROOPPED OUT” will decrease by -1.2085, which mean the higher GPA, the less likely students would drop out from MATH major. Similarly, the negative correlation between HS_GPA and ENROLLED_OTHER indicates the higher GPA, the less likely students would change their major (from MATH to other majors).

Variable	**DF**	**Estimate**	**StdErr**	**WaldChiSq**	**ProbChiSq**	**_ESTTYPE_**
MATH117	1	-1.1524	0.6045	3.6345	0.0566	MLE
MATH126	1	-1.1213	0.3152	12.6582	0.0004	MLE
MATH227	1	-0.7378	0.2120	12.1146	0.0005	MLE
MATH310	1	-0.4555	0.2340	3.7874	0.0516	MLE
MATH317	1	-0.5452	0.2856	3.6444	0.0563	MLE
MATH327	1	-0.5953	0.2465	5.8299	0.0158	MLE
MATH331	1	-0.7131	0.3573	3.9837	0.0459	MLE
MATH429	1	-0.9447	0.5736	2.7129	0.0995	MLE
MATH498	1	-0.5484	0.3293	2.7735	0.0958	MLE

Table 6: Logistic Model

The table above is the result from a Logistic Model conducted as:

Pr(G) = f(HS_GPA, Ethnicity, gender, HI_ACT_COMP,course) *cut-off P_value = 10%*

With:

- HS_GPA : GPA from high school from 0-4.
- Ethnicity: race (White =1 or other = 0)
- Gender: female = 1, male = 0.

- Hi_ACT_COPM: Composite ACT score from high school
- Course: a specific class that we are looking at

Among 77 classes offered, there are only 9 classes that have predict power on whether a student would be able to succeed in Math major. (Only Grad with math within 8 years and dropped out event are taken into account)

The negative correlation between the classes' grades and the DROPPED_OUT event shows that the higher grade students earn in those classes, the less likely they would drop out of the major.

Pr(G) = f(HS_GPA, Ethnicity, gender, HI_ACT_COMP, course grade, course grade * HS_GPA)

cut-off P_value = 10% With:

- HS_GPA : GPA from high school from 0-4.Ethnicity: race (White =1 or other = 0)
- Gender: female = 1, male = 0.
- Hi_ACT_COPM: Composite ACT score from high school
- Course grade : grades that given in a specific class that we are looking at
- Course grade * HS_GPA: interaction between high school GPA and course grade

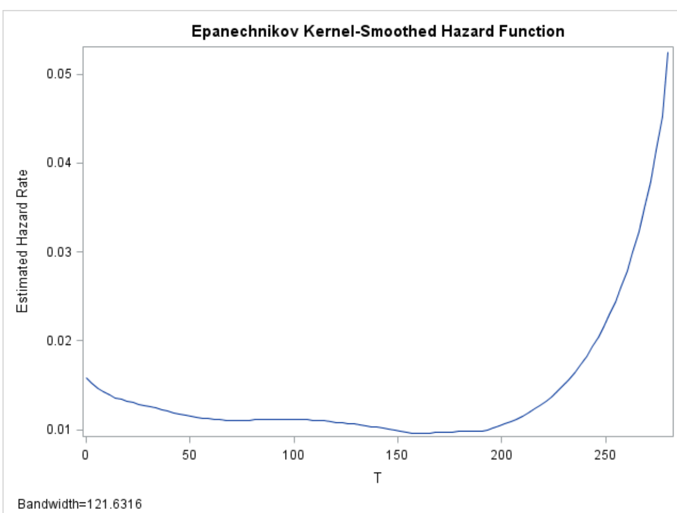
Obs	Variable	DF	Estimate	StdErr	WaldChiSq	ProbChiSq	_ESTTYPE_	odd
1	MATH109	0	0	.	.	.	MLE	1
2	HS_GPA*MATH109	0	0	.	.	.	MLE	1
3	MATH119	0	0	.	.	.	MLE	1
4	HS_GPA*MATH119	0	0	.	.	.	MLE	1
5	HS_GPA*MATH315	0	0	.	.	.	MLE	1
6	MATH415	0	0	.	.	.	MLE	1
7	HS_GPA*MATH415	0	0	.	.	.	MLE	1
8	MATH473	0	0	.	.	.	MLE	1
9	HS_GPA*MATH473	0	0	.	.	.	MLE	1
10	MATH475	0	0	.	.	.	MLE	1
11	HS_GPA*MATH475	0	0	.	.	.	MLE	1

Table 7: Logistic Model with Interaction

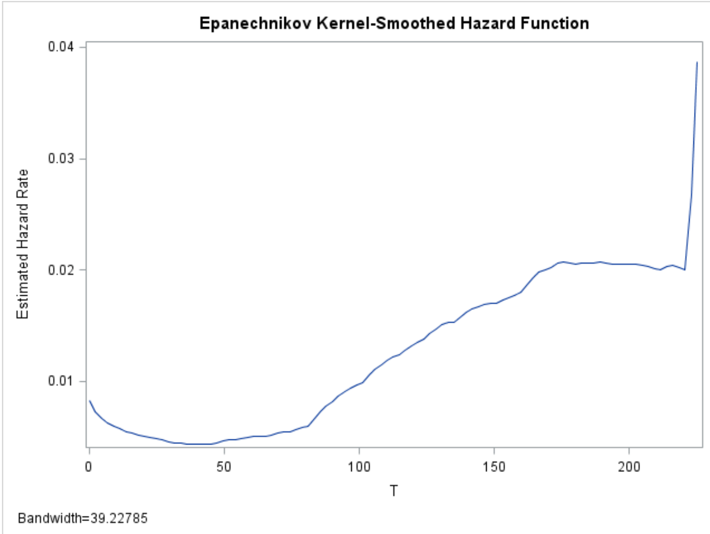
Experimental Analysis: Survival Analysis

To demonstrate how the "risk" of dropping

out changes overtime, the Kaplan-Meier method is employed. The graph bellows show the instantaneous hazard rate associated with each point in time. The duration analysis is set to be 35 units time analysis for each academic year, including Spring, Summer, Fall of the current calendar year and the winter term of the previous year.



The transition from the first year to the fourth year demonstrates a diminishing low hazard rate, meaning that among students who eventually dropped out, the risk of dropping is small for the first 4 years. However, once a student reaches the mark of his fourth year but not yet graduated, their dropping hazard increases significantly.



The risk of student switching from Math to another major is rather low during the first two years before growing fast after the completion of their second year. Students who have stayed in the program for too long (more than 5 years) are very likely to switch major.

Conclusion

We presented in this research the first part of an ongoing research in pathways to success in STEM Disciplines. We examined the effect of race and gender and other variables on graduation rate and we also looked at the impact power of some specific courses and the risk of dropping out at specific time for freshman who declared math as their major at WKU. Our future work concentrates on developing an analytic model that could show the pathways (i.e. course sequencing) to success for Math majors at WKU, thus helping to improve overall student retention and/or the retention of Math majors at WKU.

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