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Predicting Student Success in an Electrical Engineering Program

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Abstract

Successful completion of course of study leading to graduation in electrical engineering was found to be linked to a couple of key gateway courses. Students that performed below a threshold in these early courses had a lower probability of graduating and could then be identified for additional assistance. Based on these results, changes were implemented in the curriculum to enhance student success in these preliminary courses to facilitate retention.

Keywords

Student success, retention, gateway course, faculty paper

Introduction

Predicting student success based on their performance in certain fundamental courses within their first three semesters facilitated intervention to enhance retention. Electric circuits has been identified as a key gateway course which was highly predictive of students' success in their program [1]. These gateway courses occurred early in the curriculum allowing actions to be taken to assist students to complete their program. The electric circuits courses provided the basic prerequisite knowledge required in several electrical engineering upper-level courses from electronics to controls. Electric circuits I, the first of the two-course sequence, introduces the basic concepts and methods for linear circuit analysis. In an earlier study [2], factors that contributed to the students' success in Circuits I were identified. This course is included in the curriculum for both electrical and mechanical engineering majors as well as Physics and Engineering Physics. In this study, the focus was on the student majoring in the electrical and computer engineering programs and the factors that affected their successful completion.

Results

Electrical engineering students performance in the Circuit I course was observed from Fall 2010 through Fall 2017 and monitor until graduation from Fall 2012 through Spring 2021. Table 1 contains the number of students who were registered in circuits I. If a student withdrew or failed the course and registered to take it again, only their final attempt was included in the data analysis. The students were monitored until they graduated in an electrical engineering or other degree program or until the end date of the study. A successful outcome was graduation from either electrical or computer engineering. The last entry for a student participation in Circuits I was 3½ years prior to end of the study. Students following the curriculum would be expected to complete their degree within 2½ years following Circuits I which allows an addition one year for the students to complete their degree.

Table 1: Student demographics. The distribution of students in the two areas of electrical engineering (electrical and computer) at the time students completed circuits I is shown in the second column. One mechanical engineering student switched majors after circuit I and graduated in electrical engineering. An over all total of 72.5% graduated in an electrical engineering program (75.3% in either electrical or mechanical), 11.2% completed their degree in another discipline, and 16.3% did not have a record of graduation at ATU.

Major	In Circuits I	Graduation	Percent Graduation
Electrical Engineering	247	182	73.7%
Computer Engineering	47	32	68.1%
Mechanical Engineering	1		
Over All EE Programs			72.5%
Other Major		33	11.2%
No Graduation Recorded		48	16.3%
Total	295	295	

Model Selection

A logistic regression analysis was performed using the R statistical package [3]. Graduation from one of the electrical engineering programs was the outcome, or dependent variable, and the grades in Circuits I, Calculus I and II, Differential Equations, Math ACT scores, and cumulative GPA were the independent predictor variables, x_1, x_2, … in equation 1. The grades in Circuits I were significant with those in Differential Equations, close to significance as shown in Table 2.

$$logit(p) = \ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k \quad (1)$$

where

$$0 \le p \le 1 \quad \text{and} \quad \beta_i \;\; i \in [0,k] \;\; \textit{are the model coefficients}$$

Once the model coefficients are determined, equation 2 allows the probability of graduation within an electrical engineering program to be predicted for each student.

$$p = \frac{\exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k)}{1 + \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k)} \quad (2)$$

The probability of graduation was highly dependent on the Circuits I students' grades as well to a lesser extent their grades in Differential Equations. Although Math ACT scores were originally included in the model, it was not significant and reduced the number of students in the study since only approximately 75% of the students had ACT data. Since ACT scores did not contribute significantly to the prediction of graduation and were not be available for all students to predict graduation success, they were excluded from the model.

Table 2: Logistic regression results with electrical engineering program graduation as the dependent upon the grade earned in Circuits I, Differential Equations, Calculus I & II, Math ACT, and the cumulative GPA in the semester that Circuits I was taken. Only Circuits I and Differential Equations were significant and the only ones listed.

	Coefficient	Std. Error	P value	Odds Ratio	Odds Ratio 95% CI
Circuits I	0.668	0.227	0.00327	1.95	(1.26, 3.09)
Differential Equations	0.365	0.184	0.04715	1.44	(1.01, 2.08)

Several methods have been developed to select the order of the model. The two considered here are the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) with the recommended model based on the lowest score [4]. Since the grades in Circuits I and Differential Equations were the only parameters that were significant and the model with these two variable had the next to lowest AIC and and lowest BIC scores, the model with Circuits I and Differential Equation grades was selected as the one that best represented the data.

Table 3: The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) are two criterion methods for candidate model selection with the recommendation based on the lowest value.

Model Input Variables	AIC	BIC
Circuits I, Differential Equations, GPA, Calculus I and Calculus II	292.0	314.1
Circuits I and Differential Equations	292.6	303.7
Circuits I	297.8	305.2
Differential Equations	318.3	325.6

Figure 1 was obtained from the logistic regression of graduation on the Circuits I grades as the independent variable under three different conditions: students with a B or greater in Differential Equations, with a C or less, or all students regardless of their Differential Equations grade. All curves in Figure 1 are model projections over the full grade range. No student graduated with a failing grade in Circuits I. There were only a very few students who graduated with a B or greater in Differential Equation and a D in Circuits I. These results imply that students must earn at least a C in Circuits I and Differential Equations to have better than a 60% probability of graduating with an electrical engineering degree. Since Differential Equation grades became more relevant to their probability of graduation for students with Circuits I grades at the C & D level, as seen in Figure 1, this provided another reason to retained the Differential Equation grades in the model.

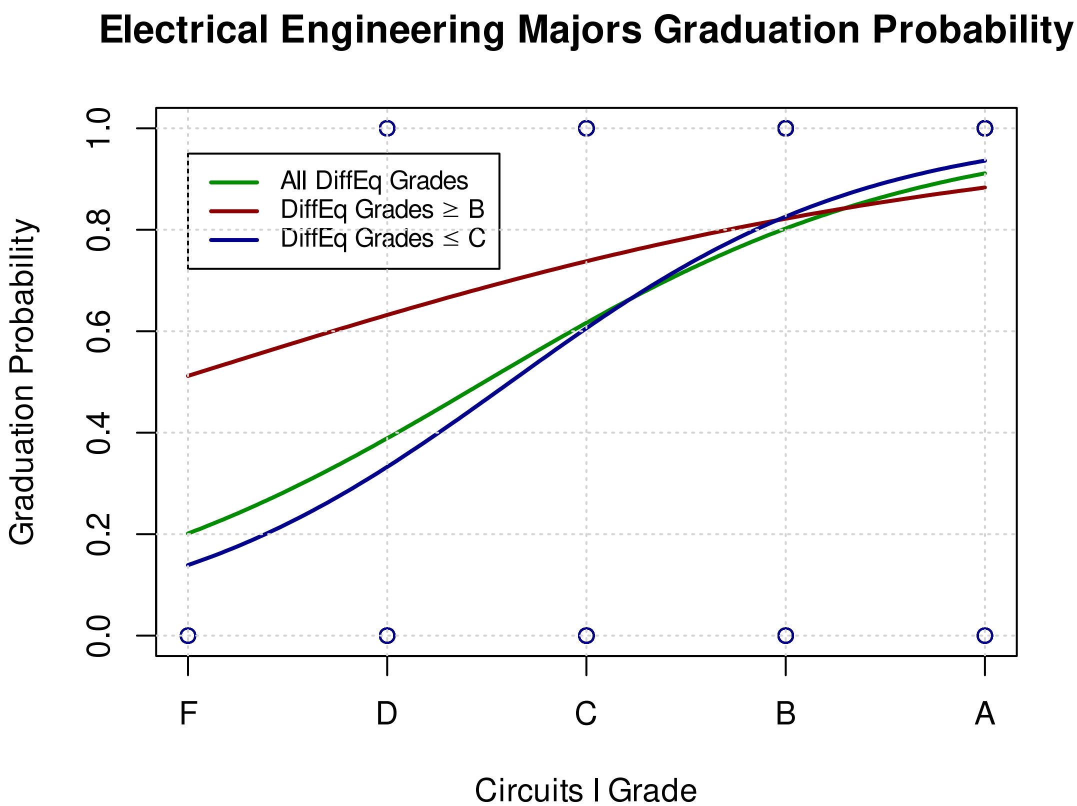

Figure 1: Graduation Probability in an electrical engineering program dependent upon the Circuits I grade. The red curve includes students that made a B or greater in Differential Equations, and the blue curve includes those that made a C or less. The green curve includes all students irrespective of their Differential Equation grade.

The prerequisite course for Circuits I was Calculus II. The probability of a achieving a C or better in Circuits I based on the graded in Calculus II is shown in Figure 2. Students who earned a C or better in Calculus II had an 80% or better probability of earning a C or better in Circuits I but only a 60% chance with a grade less than a C. The curve shown in Figure 2 represents the projection of the model to the data over the full grade range. Students could not take Circuits I until they obtained a passing grade in Calculus II. Establishing C as the minimal grade in Calculus II as the prerequisite for Circuits I would enhance the students probability of success in Circuits I and ultimately graduation from an electrical engineering program.

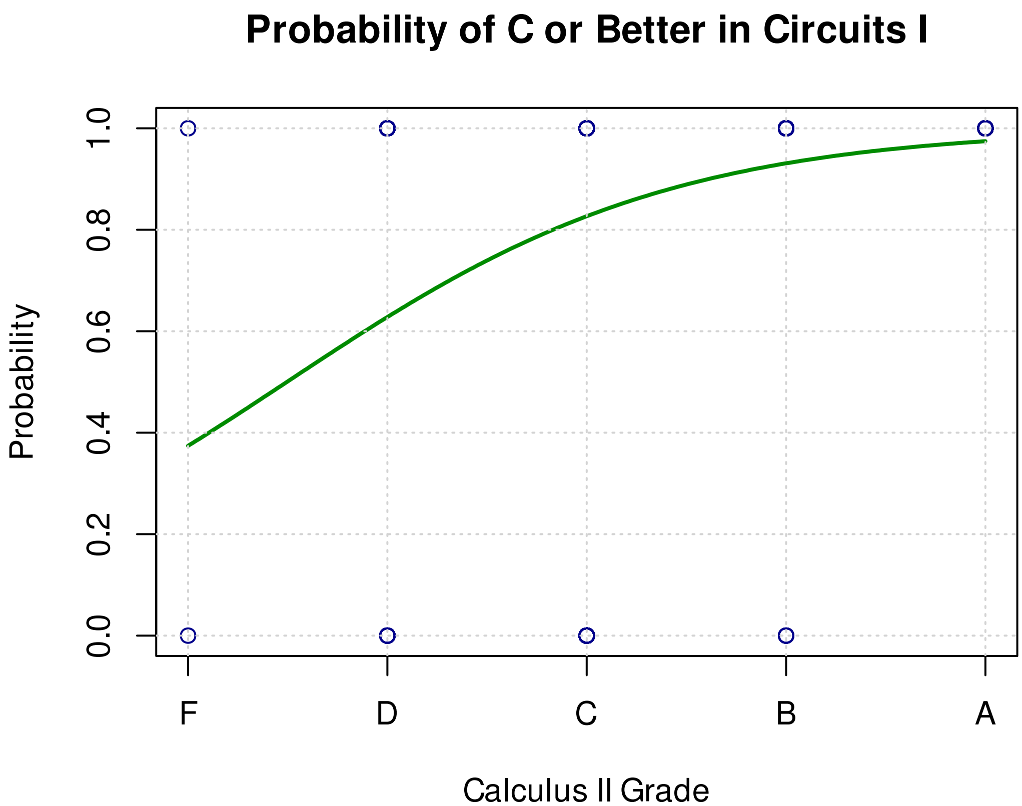

Figure 2: Probability of achieving a C or better in Circuits I based on the students' grades in the prerequisite Calculus II course. Line represents the best fit to the logistic model projected over the full range of grades. A passing grade was required in Calculus II to be eligible to register in Circuits I.

Model Validation

Model validation was determined by randomly separation of the data into training and testing sets. The training set was used to obtain the model parameters which were then used in the testing set to predict the probability of successfully graduating within an electrical engineering program and compared to the recorded outcomes for verification. The results of the model with parameters obtained from the training set on the data in the testing set were probabilities of graduation ranging from 0 to 1. Establishing a threshold of say p = 0.5 allowed the model predictions to be compared to the actual results in the testing set. If the probability prediction was greater than the threshold, a successful graduation outcome was predicted which was compared with the actual results. These results yield the confusion matrix as shown in Table 4.

Table 4: Confusion Matrix for Graduation Prediction Model where TN = True Negative, FN = False Negative, FP = False Positive, TP = True Positive

	Prediction		
True Status	**Fail**	**Success**	Total
Fail	TN = 16	FP = 16	N = 32
Success	FN = 5	TP = 81	P = 86
Total	21	97	118

The confusion matrix could then be used to evaluate the model. The model Sensitivity or True Positive Rate is TPR = TP / (TP + FN) = 0.942 in this case, and the Specificity or True Negative Rate is TNR where TNR = TN / (TN + FP) = 0.5. Specificity is also equal to 1 – FPR where FPR = FP / (FP + TN) = 0.5, and the Accuracy = (TN + TP) / (P + N) = 0.822. Ideally, both sensitivity and specificity should be close to 1. There are several reasons for the relative large False Positive Rate (FPR) in this study. Only student that graduated with a degree in one of the electrical engineering programs was considered a positive outcome. Of the students that graduated, five changed majors from electrical engineering to mechanical engineering after completing the Circuits I course where only one switched from mechanical to electrical. Several changed their major and completed their degree in another STEM area (i.e., Math, Physics, Computer Science). In addition, several students transferred to another university and were not tracked. These students would have likely been predicted to graduate in an electrical engineering program but were not counted as a positive outcome since they graduated in another discipline or could not be tracked.

The confusion matrix depends on the selected probability threshold. Utilizing the testing data set, the p value from equation 2 was compared with two other thresholds to predict graduation. Table 5 contains these Sensitivity, Specificity, and Accuracy results from the probability thresholds of 0.4, 0.5, and 0.6.

Table 5: Sensitivity, Specificity, and Accuracy for three probability thresholds

	p = 0.4	**p = 0.5**	**p = 0.6**
Sensitivity (TPR)	0.988	0.942	0.872
Specificity (1 - FPR)	0.406	0.50	0.531
Accuracy	0.831	0.822	0.780

The full range of the model's Sensitivity and Specificity values would be obtained by selecting the probability threshold over its full range from 0 to 1. The Receiver Operating Characteristic (ROC) curve displays this information as shown in Figure 3 with the p threshold as the intrinsic parameter defining points along the ROC curve. An ideal binary classifier would have an ROC curve that approached the upper left hand corner with an area under the curve (AUC) → 1.

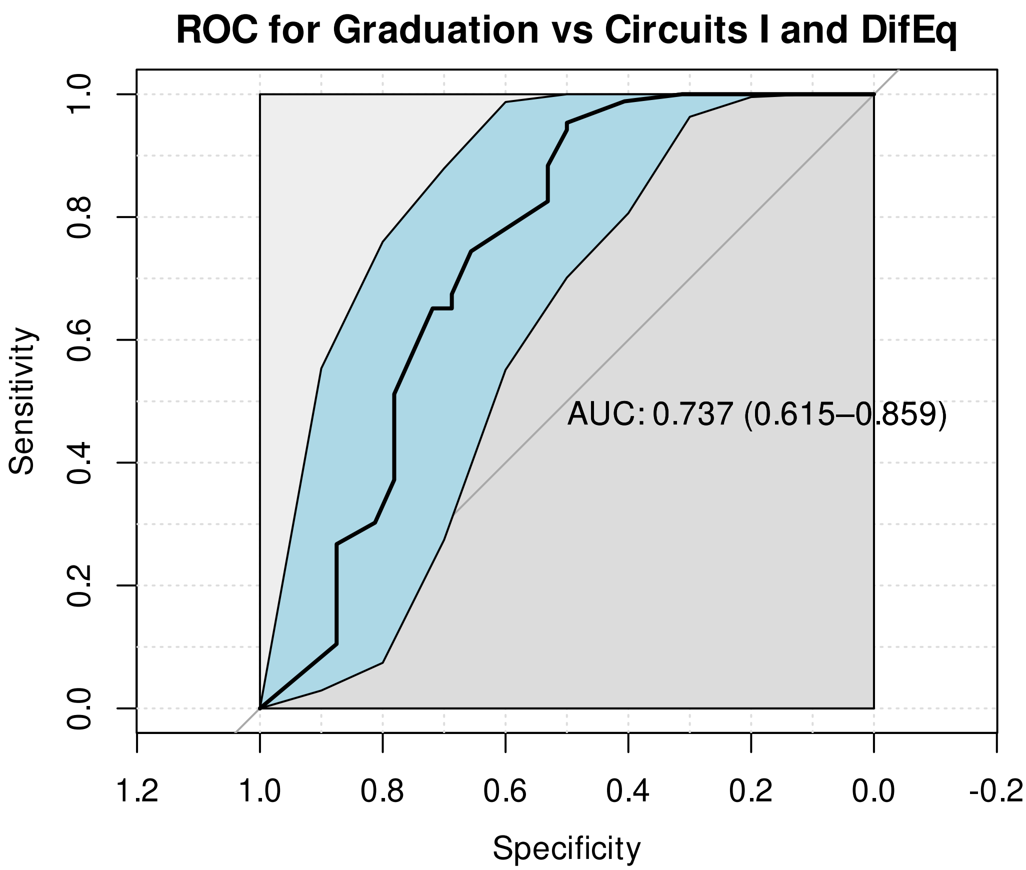

Figure 3: ROC curve for predicting graduation in an electrical engineering program based on the grades the students received in Circuits I and Differential Equations.

Conclusions

The performances in certain key gateway courses were highly related to the students' successful completion of their degree plan. Students that earned a C or less in both Circuits I and Differential Equations had less than a 60% probability of graduating in electrical engineering whereas students with a B or higher in Circuits I had a 80 to 90% probability of graduating with an electrical engineering degree. It was found that students who earned a C or better in Calculus II, a prerequisite to Circuits I, had an 87% probability of earning at least a C in Circuits I. Since a C in Circuits I was the minimum threshold for a successful completion of the degree, the prerequisite was changed from a passing grade to require a C or better in Calculus II. Plans are currently in the development stages to assist students that earn a C or less in both Circuits I and Differential Equations.

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Dr. Greco is a Professor of Electrical and Computer Engineering with research interest in biomedical signal processing. He teaches courses in digital systems, signals and systems, communications and biomedical signal processing.

Dr. Matthew Garett Young

Dr. Matthew G. Young received his B. Sc. in Electrical Engineering from Arkansas Tech University in 2009. He participated in an NSF IREU focusing on antenna design in the summer of 2009 before obtaining his M. Sc. in Microelectronics-Photonics at the University of Arkansas in 2012. For his M. Sc. studies, he focused on the growth of silicon nanowires via plasma enhanced chemical vapor deposition. In August of 2016, he joined the faculty at Arkansas Tech University as an Assistant Professor of Electrical Engineering. His Ph.D. was completed at the University of Arkansas in May 2017. At Arkansas Tech University, Matthew is focused on establishing research experiences in photovoltaics for undergraduate and graduate students and investigating new methods to enhance engineering education in the classroom.