Analyzing Factors for First Semester General Chemistry Student Success at the University of Central Oklahoma

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Abstract: Student success in the first semester of general chemistry is crucial for not only STEM majors, but also all student's basic scientific understanding. The University of Central Oklahoma (UCO) Department of Chemistry, like many other regional universities, observes a historically high D, F, and Withdrawal (DFW) rate in this course. In order to address this DFW rate and increase student success and therefore retention, we implemented a presentation on metacognitive learning strategies during the course. Furthermore, we analyzed numerous variables that may affect the success of first semester general chemistry students using departmental and university data including the use of this presentation. This was compared to prior semesters, which did not receive this presentation. This presentation focused on learning strategies and study techniques that can be practically applied in the class. We fit a multiple linear regression model and a random forest model using these variables to predict the students' percentile on their final standardized American Chemical Society (ACS) General Chemistry First Term Exam. Neither model indicated that the presentation had a statistically significant effect on ACS exam percentile, while the Math ACT score had the largest effect.

Introduction

The first semester general chemistry course at the University of Central Oklahoma (UCO) historically has high D, F, and Withdrawal (DFW) rates not dissimilar to other regional institutions around the country. Generally, there is an interest in decreasing these rates and increasing student success without decreasing standards. As a means of combatting the high DFW rates, the Department of Chemistry at UCO incorporated a learning intervention into all first semester general chemistry classes aimed at giving students insights and tools for being more effective at learning and studying. Generally, instructors are reluctant to add

material to their already quick-paced, entry-level classes. However, department instructors suggested that students could benefit from explicit instruction on how to study effectively in addition to the subject material. This led the department to explore research into presentations created by Sandra McGuire in an attempt to address these issues. The presentations or learning interventions were based on *Teaching Students How to Learn: Strategies You Can Incorporate into Any Course to Improve Student Metacognition, Study Skills and Motivation.* (McGuire 2015) In the book, she suggests that arming students with the knowledge of how to learn in addition to providing "simple, straightforward strategies to use" empowers students to increase their learning retention and performance in any class. Most studies to-date focus on improving teaching methods and subsequently student performance. These practices are instructor dependent. This presentation aims to put the power back in the hands of the student (instructor independent), not only helping them in a specific class, but with their entire college education (Cook et al., 2013). These strategies are aimed at improving student metacognition or "students thinking about their own thinking". Improving student's metacognition has been shown to aid in deeper and more long-term retention of the subject matter (Bransford et al., 2004, Zhao et al.,2014). The presentation was given to first semester general chemistry students after they received their graded first exam of the semester, with the hope that having seen the presentation, the students would apply what they learned, and their success rates would improve over the semester. To determine whether the presentation on metacognitive strategies for studying has led to an improvement in the performance of students taking first semester general chemistry, we analyzed current and historical data collected by the UCO Department of Chemistry that have numerous categorical and quantitative variables. This includes the students' final exam percentile, which is the standardized American Chemical Society (ACS) General Chemistry First Term Exam and is a good predictor of student success.

Methods

Data Collection

Over the last few years, several professors in the Department of Chemistry gave the metacognitive strategies presentation to their students after having completed the first exam of the semester. Each student, as their final exam in the class, was required to take the ACS General Chemistry First Term Exam which is a nationally standardized exam. Each student's results were recorded by the UCO Department of Chemistry. Additionally, demographic information for the students was obtained through access to the students' enrollment profiles with UCO. The complete list of variables used in the analysis can be found in Figure 1. Several steps of data processing were required since the data was combined from multiple sources. Duplicate entries were removed and students without recorded ACS exam scores were deleted. This resulted in a total sample size of 1,010 UCO students over 6 consecutive semesters. Finally, the raw ACS exam scores were converted to percentiles using national data based on the year that the exam was administered (ACS Exam, 2016).

Model Creation

Two different models were used to predict ACS exam percentiles. These initial analyses both utilize multivariate techniques in order to account for the influence of potential confounding variables such as prior academic success and a variety of demographic attributes. First, a traditional multiple linear regression model was fit to the data. This approach enables one to perform hypothesis tests to examine the statistical significance of predictors, such as the indicator for the metacognitive strategies presentation, while controlling for other variables. Next, a random forest model was used to predict student performance using the same set of variables (Breiman 2001). Random forests are flexible, nonparametric models that inherently model complex interactions between predictor variables. The random forest procedure produces variable importance scores that are used to rank the predictor variables.

The full dataset was divided into training and test sets. The training set consisted of 80% of the observations while the test set contained the remaining 20%. The multiple linear regression model and random forest were both fit using the training data. The resulting models were then used to predict the ACS exam percentiles for the observations in the test set. Finally, the mean squared error (MSE) was calculated for each model using the test data. This allows for the comparison of the two models. A model with a smaller MSE is preferred.

Results and Discussion

For the multiple linear regression model results, the primary interest was in determining whether there was a significant difference in ACS exam percentiles between students who were exposed to the metacognitive strategies presentation and those who were not. The t test for the regression coefficient associated with the presentation indicator variable produced a p-value of 0.30, which is not statistically significant using $\alpha = 0.05$. Therefore, there was insufficient evidence to conclude a difference in mean ACS exam percentiles for students who did and did not receive the presentation. The multiple regression model had an adjusted R^2 value of 0.3472 and produced an MSE of 451.95 on the test set.

The random forest model more accurately predicted the ACS exam percentiles for the data in the test set with an MSE of 390.33. Unfortunately, traditional hypothesis tests are not readily available for random forest models. Nevertheless, the influence of predictor variables can still be assessed by calculating variable importance scores. These values measure the percentage of the increase in MSE after randomly permuting values for the predictor variables. Shuffling the values of a significant variable will cause a greater increase in MSE than shuffling values for a variable that is not significant. If the metacognitive strategies presentation is significant in predicting ACS exam percentiles, then randomly permuting that variable will increase the prediction errors thus resulting in that variable having a large importance score. The resulting variable importance scores from the random forest model can be seen in Figure 1. The presentation indicator variable was ranked eighth out of the fifteen independent variables. This middle-of-the-pack finish suggests that the presentation was not one of the most important variables for predicting student ACS exam percentiles.

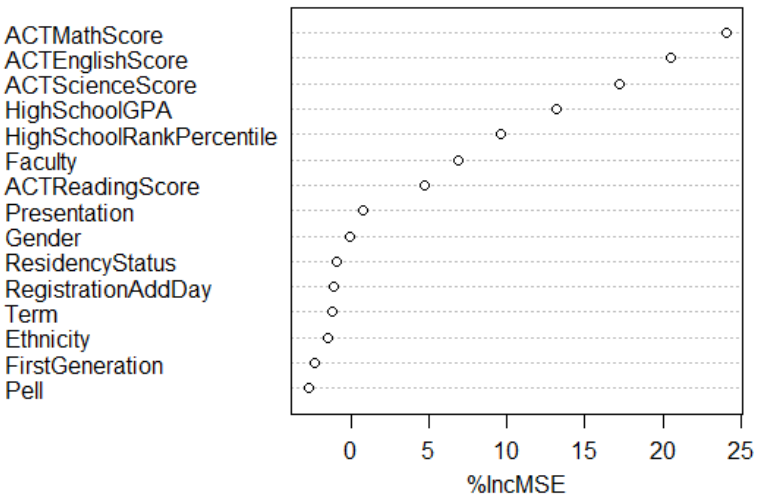

Figure 1. Plot showing the variable importance scores calculated from the random forest model. The percentage increase in MSE is shown on the horizontal axis. The vertical axis contains the list of independent variables ranked from most important at the top to least important at the bottom.

Neither model indicated that the metacognitive strategies presentation had a significant impact on ACS exam percentiles after controlling for the other variables. Box plots showing the distribution of the ACS exam percentiles for students receiving and those not receiving the presentation were created in order to get a simpler look at the effect of the presentation. These plots can be seen in Figure 2. From the box plots, it appears that the distributions of percentiles are nearly identical for both groups of students. The median percentile of students who received the presentation was marginally higher than the median of those in classes that did not have the presentation, but it is reasonable to conclude that difference is not statistically or practically significant. This does not mean that the presentations were not effective for individual students. While the overall trend is not statistically significant, anecdotal evidence from individual instructors with certain individual students has shown that the presentations were helpful. While we know this learning intervention helps individual students, we are still exploring ways to make it more effective for the entire general chemistry first semester population. One option we have considered is giving the initial metacognition talk after the first exam and then following it up every other week with a ten-minute refresher talk. This talk would remind students of metacognition and introduce an additional learning technique that they might find beneficial.

The score on the Math section of the ACT had the largest variable importance score from the random forest. This suggests that ACT Math score is among the most important variables in predicting student ACS exam percentiles. The results from the multiple linear regression model support this conclusion as the hypothesis test for the regression coefficient for ACT Math score showed statistical significance with $p < 0.001$. This result is not surprising as previous research has identified a relationship between ACT Math scores and success in first semester general chemistry and other Science, Technology, Engineering and Math (STEM) fields in general (Cook et al., 2013, Ralph et al., 2018, Elliott et al., 2001).

An additional simple linear regression model was fit using only ACT Math to predict ACS exam percentile in order to further explore the relationship between these variables. A scatterplot showing the positive relationship between these variables as well as the fitted regression line with corresponding standard errors can be seen in Figure 3. The resulting predicted value of ACS exam percentile can be

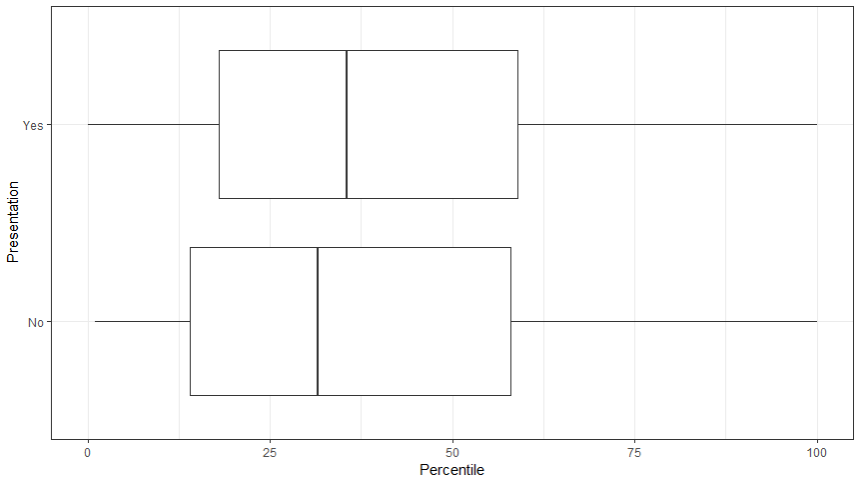

Figure 2. Box plots showing the distribution of ACS exam percentiles for students enrolled in classes that received the presentation (YES) and those enrolled in classes not receiving the presentation (NO).

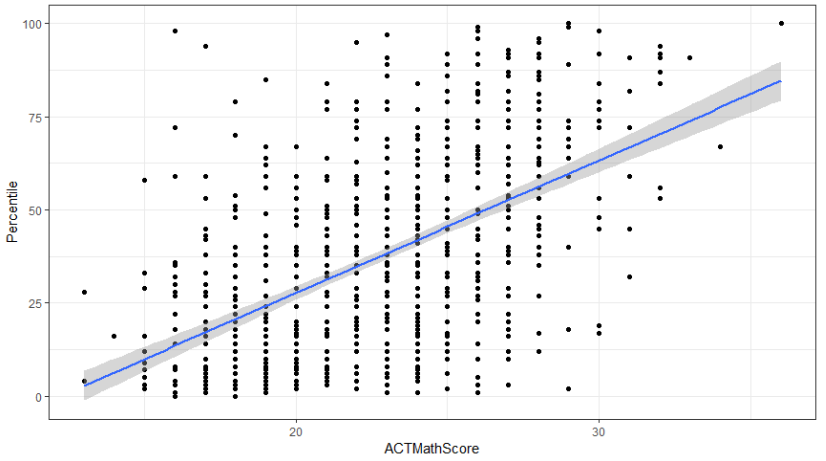

Figure 3. Scatter plot showing the relationship between ACT Math score on the horizontal axis and ACS exam percentile on the vertical axis. The resulting regression equation is included with corresponding 95% confidence band.

calculated from the following:

The model indicates that students with an ACT Math score of approximately 21 or greater can be expected to meet the 30th percentile cutoff on the ACS Exam. This cutoff was chosen based on historical student performance in first semester general chemistry at UCO. Students who performed under the 30th percentile on the ACS Exam were unlikely to be successful in completing the course with a passing grade.

The models showed that there were several variables that were significant in predicting ACS exam percentile. Both models indicate that ACT Math Score is the most significant predictor of ACS exam percentile. Other variables that were determined to be significant in both models are ACT Science, ACT English, High School GPA, and High School Rank Percentile. Notably, the presentation on metacognitive strategies was not deemed to be a significant predictor of ACS exam percentile in either model. While the presentation was not a significant difference for the average of the class, there may be individual students who benefited from this presentation. At the very least this data indicates that students do not perform worse on average despite using a significant amount of class time for these presentations. In the future probing individual student performance with and without the presentations could yield more specific results on which students are being positively or negatively affected. For example, we evaluated a student's final exam percentile as a proxy for student success without including other classroom assessments, like unit exams, which may tell a more nuanced story. It must also be mentioned that other methods of treating missing data, as opposed to deleting these entries, could allow for more data and may lead to different models for predicting student success. The addition of this missing data would include all students that are counted in the DFW rate, rather than only those that took the standardized ACS final. This may also help elucidate the connection between math proficiency and overall success in general chemistry.

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