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Innovative approach for teaching the receiver operating characteristic (ROC) curve

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Abstract

A current trend within the healthcare sector is the use of predictive analytics to aid in medical decisions. One popular analytical method for testing the accuracy of diagnostic test or markers is the Receiver Operating Characteristic (ROC) curve. The ROC curve expands upon logistic regression, which is a difficult concept for many students to grasp. As a result, the ROC curve is rarely taught in a typical analytics course because of its difficulty to understand. To provide an innovative approach for educators to teach the ROC curve to undergraduate students, this paper provides a sample teaching aid regarding real-world case studies. This research has practical impacts for analytics practitioners, faculty, students, and future authors.

Keywords: predictive analytics, ROC curve, healthcare analytics, teaching methodology, case studies for teaching aids

Introduction

In today's rapidly changing economic, health, and environmental climate, the use of predictive analytics is essential to aid an organization's ability to better identify future risks or opportunities (Lawton et al., 2022). Regression analysis is one of the popular tests used for predictive analytics (Kumar & Greg, 2018; Columbia University, 2023; Lawton et al, 2022). However, regression often lacks the ability to provide a range of possible cut points that can yield to be useful in specific instances. The ROC curve provides a range of possible points (Columbia University, 2023).

The ROC curve originated in the 1950s and is commonly used to illustrate the diagnostic ability of binary classifiers and evaluate classifiers for predicting rare occurrences (Sachs, 2017; Perez and Perez, 2023). Thus, it is commonly used within the healthcare, natural hazards, and analytics/machine learning fields. While the ROC curve, is not a new concept, the use of how it is being applied and used today in various fields of study is new and trending (Moon, 2023; Shen et al., 2023). Today, the ROC is the preferred analytical test for accuracy of medical diagnostic systems because its accuracy is not contorted using cut-offs or specific thresholds (Perez and Perez, 2023). Additionally, as the trending complexity of diseases and virus like COVID-19 becomes more apparent, physicians, nurses, and other healthcare employees need to utilize analytics to aid in discovery of diagnoses, treatment, and prevention (Jameson and Longo, 2015; Shen et al. 2023).

To prepare students for analytic employment opportunities within the healthcare sector, the ROC curve is an essential concept that should be taught in analytics courses (Campo et al., 2010; Reid, et al, 1998) proceeding logistic regression. Specifically, when there is a dichotomous logistic regression outcome, the ROC curve will be helpful in expanding upon the outcome. However, the problem occurs in that many analytics classes don't cover logistic regression let alone cover ROC curves. A recent study by Kunene and Toskin (2022) reviewed 50 random statistics/analytics syllabi from various universities for the learning objective of logistic regression. They found that only 1 out of the 50 courses covered logistic regression. They argued that it is not often covered due to its complexity. They suggested multiple solutions including developing innovative, and easy to understand learning materials.

Since the ROC curve expands upon logistic regression, one can assume the same may be happening with the learning of the ROC curve. Reid et al. (2018) surveyed 300 practicing physicians regarding their understanding of predictive analytic topics including the ROC curve. They found that 97% had no familiarity with the ROC curve. Reid et al argued that ROC curve must be taught in college. Moreover, Eng (2012) believes that while the ROC is an essential concept to learn, it is often overlooked because it is a difficult concept for students to understand. As a result, students are lacking the understanding of the trending ROC curve concept (Reid et al., 2018).

A current review of the existing literature finds a lack of innovative teaching tools or guidelines for aid educators in teaching the ROC curve. Thus, there is a need to provide innovative teaching tools which aid educators in breaking down the ROC curve concept in simple terms so that students can better understand the concept and be better prepared for employment opportunities. This paper provides a current review of the ROC curve concept to help add to the body of literature by providing an innovative case study method for students to better understand and comprehension of the ROC curve and its use within the healthcare analytics field. The remainder of this paper is as follows: a brief literature review, followed by the case study methods in the form of a teaching tool, and concluding with limitations and future research.

Brief Literature Review

There are various types of ROC Curves. However, two of the most popular ROC curves are nonparametric/empirical and parametric/binormal. The nonparametric/empirical ROC curve is known as a smooth curve because actual data points are not used within the plotted graph. On the other hand, a parametric/binormal ROC curve uses all data points for the plotted graph. As a result, a parametric ROC curve often has a rough or unsmooth curve. Each ROC curve has its advantages and disadvantages (Nahm, 2022; Sachs, 2017).

Nonparametric or Empirical ROC

A nonparametric ROC analysis is clear in not making any assumptions about the underlying distribution of the data. Instead, it is based solely on the ranking of the continuous variable (Nahm, 2022; Sachs, 2017). Within the healthcare sector, a continuous variable may be a test result or identified marker. Currently, a nonparametric analysis is one of the most dominant ways to assess the diagnostic accuracy of a continuous variable in distinguishing between two or more diagnostic groups (Sachs, 2017). As a result, it is a highly flexible and robust method that is often applied to a wide range of data types and sample sizes. For example, in a study by Cho et al. (2021), nonparametric ROC analysis was used to evaluate the diagnostic accuracy of multiple blood biomarkers for predicting mortality in COVID-19 patients. Similarly, Shen et al (2023) also utilized a nonparametric ROC analysis in their study which summarized and combined diagnostic performance measures of multiple COVID-19 studies.

One of the main advantages of nonparametric ROC analysis is its ability to generate accurate and unbiased estimates of the area under the ROC curve (AUC), which is a widely used measure of diagnostic accuracy (Nahm, 2022; Sachs, 2017). Additionally, a nonparametric ROC analysis is also useful in handling censored data, where the outcome is not directly observed for all participants (Heagerty & Zheng, 2005). For example, in a study by Bhalla et al. (2021), nonparametric ROC analysis was used to assess the diagnostic accuracy of a urinary biomarker in predicting the onset of acute kidney injury (AKI) for critically ill patients. It accounted for censoring due to death or discharge from the hospital. The nonparametric ROC analysis revealed that a urinary biomarker can be used for predicting AKI onset.

Parametric or Binormal ROC

Unlike nonparametric approaches, parametric ROC analysis assumes a normal distribution for the test values and estimates the parameters of the distribution from the data. Thus, it provides unbiases estimates of sensitivity & specificity. As a result, it is a more efficient method than nonparametric approaches when the normality assumption is appropriate (Nahm, 2022; Sachs, 2017). For example, in a study by Lin et al. (2021), parametric ROC analysis was used to evaluate the diagnostic accuracy of a novel imaging biomarker for predicting the risk of lymph node metastasis in patients with breast cancer.

Parametric ROC analysis can also be used to model the relationship between the test variable and other covariates, such as age, gender, or disease stage (Nahm, 2022; Sachs, 2017). This allows for the estimation of adjusted ROC curves that account for the effects of these covariates on the diagnostic accuracy of the test variable. For example, in a study by Kim et al. (2021), parametric ROC analysis was used to estimate the adjusted ROC curve of a blood biomarker for predicting the risk of cardiovascular disease in middle-aged Korean adults. The analysis showed that the diagnostic accuracy of the biomarker was significantly improved after adjusting for age, gender, and other cardiovascular risk factors.

One of the main advantages of parametric ROC analysis is its ability to estimate the optimal cutoff value for the test variable, which is the value that maximizes the sum of sensitivity and specificity. This cutoff value can be used to classify patients as either positive or negative for the disease based on the test results (Nahm, 2022; Sachs, 2017). In a study by Li et al. (2021), parametric ROC analysis was used to determine the optimal cutoff value for a blood biomarker in diagnosing hepatocellular carcinoma. The results showed that the optimal cutoff value had a high sensitivity and specificity, indicating that the biomarker may be a useful tool for diagnosing the disease.

Case Studies Method

As mentioned earlier, Kunene and Toskin (2022) suggested using an innovative and easy to understand learning aid to help cover complex statistical and analytic topics. Additionally, research also suggests that case studies help students to better understand how and why something is done or being used in the “real word” (Boston University Center for Teaching and Learning, n.d.). Due to the complex nature of the ROC curve topic, we suggest using case studies to only explain the ROC Curve.

Reading the entire case study could be daunting and a lengthy process. However, an innovated approach is to have students focus on the abstract, introduction and purpose/hypotheses/research questions to help make reading a ROC curve study a simple task. Table 1 provides a list of three of the authors’ favorite healthcare studies that use the ROC Curve. Each of these cases briefly explains the ROC curve and provides a purpose or statement as to what the ROC is testing. Thus, these three articles are used to help students understand what, why, and how the ROC curve can test and measure.

Table 1: Sample Articles/Case Studies

General Area of Study	Article Resource
Brain Injury/Trauma	Main. K.L, Soman, S., Pestilli F, Furst, A., Noda, A., Hernandez, B., Kong, J., Cheng, J., Fairchild, J. K., Taylor, J., Yesavage, J., Wesson Ashford, J., Kraemer, H., Adamson, M.M. (2017). DTI measures identify mild and moderate TBI cases among patients with complex health problems: A receiver operating characteristic analysis of U.S. veterans. *Neuroimage Clinical*. 24 (16), 1-16.
	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5503837/
Carpal Tunnel	Lee, S. Cho., H.R., Yoo, J.S., Kim, Y.U. (2020). Lee S, Cho HR, Yoo JS, Kim YU. The prognostic value of median nerve thickness in diagnosing carpal tunnel syndrome using magnetic resonance imaging: a pilot study. *Korean Journal of Pain*, 33, 54-59.
	https://www.epain.org/journal/view.html?doi=10.3344/kjp.2020.33.1.54
Ovarian Cancer	Partheen, k., Kristjansdottir, B., & Sundfeldt, K. (2011). Evaluation of ovarian cancer biomarkers HE4 and CA-125 in women presenting with a suspicious cystic ovarian mass. *Journal of Gynecology Oncology*. 22(4), 244-52.
	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3254843/

Table 2 is the general sheet that is provided to the students. It provides what is tested in each case study listed in Table 1. Students are tasked to read the abstract, intro, and purpose/research questions to see what, why, and how the ROC curve is being used in each case study. Students can complete this process and a induvial, pairs, or as a class. Either way is acceptable and effective.

Table 2: Student Handout -What is Tested in the Article/Case Study

General Area of Study	What is Tested in the Article/Case Study Resource
Brain Injury/Trauma	
	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5503837/
Carpal Tunnel	
	https://www.epain.org/journal/view.html?doi=10.3344/kjp.2020.33.1.54
Ovarian Cancer	
	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3254843/

Table 3 contains the answers to what, why, and how of the ROC curve in each case study/article. For readability purposes the table only shows the first 2 case studies and what a sample result should look like. Once students complete this sheet, it can be examined to express a common theme or definition of what a ROC curve is and tests.

Table 3: Instructor Answers to Student Handout – What is tested in the Article/Case Study

General Area of Study(s)	Testing
Brain Injury/Trauma	In the U.S. military, the rigors of training along with the dangers of combat can cause thousands of traumatic brain injuries (TBI). As a result, there is a compelling need to develop objective and reliable methods for diagnosing and predicting TBI outcomes. -A nonparametric ROC curve is being used to explore the diagnostic accuracy measures. - No hypothesis testing. - Measuring the accuracy of DTI in Veteran patients who were diagnosed with or without TBI.
	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5503837/
Carpal Tunnel	The median nerve cross-sectional area (MNCSA) is a useful morphological parameter for the evaluation of carpal tunnel syndrome (CTS). - A parametric ROC curve is used to measure MNCSA and MNT at the level of the hook of hamate on CTMRI. - Measuring the accuracy of MNCSA and MNT at the level of the hook on CTMRI in 20 patients diagnosed with CTS.
	https://www.epain.org/journal/view.html?doi=10.3344/kjp.2020.33.1.54
Ovarian Cancer	This study examines women with a large or complex ovarian cyst measuring the biomarkers HE4 and CA-12. - A ROC curve was used to aid in the accuracy of determining the appropriate level of care for women who exhibit a substantial or intricate ovarian cyst.
	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3254843/

Next in table 4 a definition of the ROC curve purpose is provided. As a class the definition is broken down into simpler terms. In summary the goal is to conclude that an ROC curve looks at the effect of something in subjects who also underwent some treatment or test.

Table 4: Breaking Down the Definition of ROC Curve

Broad cited definition: "The ROC curve aims to classify a patient's disease state as either positive or negative based on test results and to find the optimal cut-off value with the best diagnostic performance. The ROC curve is also used to evaluate the overall diagnostic performance of a test and to compare the performance of two or more tests" (Nahm, 2022).
Definition broken down into simpler terms: An ROC curve measures the accuracy of something as a test for a rare impairment/condition/function.
Concluding simplest definition: ROC curve looks at the effect of something in subjects who also underwent some treatment or test.

While explaining the definition, it is also essential to discuss that the ROC curve plots sensitivity against specificity for different cutoff values of the accuracy of something (level). Thus, the explaining and interruption of sensitivity, specificity, and cut off values will need to be explained. Specifically, sensitivity is explained as the proportion of subjects (patients) who have a target (disease/impairment/condition/ function) that tested positive. Specificity is the proportion of subjects (patients) who do not have a target something (disease/impairment/condition/function) that are tested negative. Finally, the best cutoff is explained as the highest sensitivity and lowest specificity found.

Moreover, a False Positive (FP) and a False Negative (FN) are also explained. Specifically, a FP refers to the proportion of people that do not have something (disease/impairment/condition/function) but incorrectly tested positive. Similarly, there can be a false negative. On the other hand, a FN refers to the proportion of subjects (patients) that have the something (disease/impairment/condition/ function) but incorrectly tested negative (Nahm, 2022). Figure 1 provides Nahm's (2022) visual representation of how the ROC curve measures the accuracy of something as a test for a rare disease, condition, or function. Figure 1 also includes how sensitivity, specificity, and accuracy are measured.

The Decision Matrix

		Predicted condition	
		Test (+)	Test (-)
True condition	Disease (+)	a	b
	Disease (-)	c	d

The receiver operating characteristic curve is drawn with the x-axis as 1 - specificity (false positive) and the y-axis as sensitivity. sensitivity = a / (a + b), specificity = d / (c + d), false negative = b / (a + b), false positive = c / (c + d), and accuracy = (a + d) / (a + b + c + d).

Figure 1: Nahm's (2022) Visual Representation of ROC Curve Measurements of Sensitivity, Specificity, and Accuracy

As explained above, once the basic concepts have been explained to the student, the actual hands-on computing the ROC curve can begin. Starting with free online (Cloud-based) tools that compute the ROC curve for any smaller dataset is computed using the MIT License (MIT) (https://sachsmc.shinyapps.io/plotROC/) and the Johns Hopkins University School of Medicine's ROC Analysis (http://www.rad.jhmi.edu/jeng/javarad/roc/JROCFITi.html). These two online tools are chosen to be used because they are simple and straight forward, require no coding, and instantly provide an ROC Curve for the data set loaded or inputted. Additionally, it is important for the students to see that the computation of the ROC curve is valued within two prestigious IT and healthcare organizations.

Next, it is suggested that one utilizes R Studio and explain some of their favorite packages used for computing the ROC curve. Within the Comprehensive R Archive Network (CRAN) website many ROC curve packages exist. Specifically, the ROCR package is a great package to plot FPF and TPF (Nahm, 2022; Sing et al., 2005). The pROC package aids in plotting cutoff labels with shaded confidence regions (Nahm, 2022; Robin et al., 2011). Additionally, a simpler ROC plot can be found using the plotROC package (Nahm, 2022; Sachs 2017). Finally, after the basic understanding of the ROC Curve, some additional topics that should be addressed include AUC, partial AUC, likelihood ratios, Youden index, spectrum and bias and confounding issues.

Conclusion

The ROC curve is a trending topic within the healthcare industry. As a result, it needs to be taught within an analytics classroom. This research provided a review and a case study method for analytic educators to better explore and explain the ROC Curve to students in an innovative way. This research has practical impacts for analytic practitioners, faculty, students, and future authors.

However, it is important to note that this research is not without limitations. First, it is limited to literature and examples within the healthcare field. Other trending areas of interest may provide additional educational understanding of the ROC curve. Secondly, this study is based on a literature review rather than gathering of empirical evidence for analysis. Accordingly, the methodology lacks some rigor in providing answers to the research question at hand. An experimental kind of methodology would be more appropriate to apply and gauge the differences in students' comprehension of the ROC phenomenon. Third, this study was literature based providing a sample methodology for teaching the ROC curve from a healthcare analytics perspective. Different sample case studies should also be provided for additional disciplines besides healthcare. Finally, no data was collected regarding the effectiveness of the methodology. This study could be improved through future research which involves a control group to see the differences in their understanding of the concept. Additional future research studies should address the limitations described above and reevaluate the content as needed.

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