TARAN-AWAN
Journal of Educational Research and Technology Management

Vol. 1, No. 1, 2020, pp. 49 - 57
ISSN: 2719-0587

Application of machine learning algorithms in predicting the performance of students in mathematics in the modern world

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Article History
Submitted: 14 June 2020
Revised: 24 November 2020
Accepted: 10 December 2020

Abstract

The purpose of this study is to predict the performance of students in mathematics in the modern world using different machine learning algorithms. In this study, multiple linear regression, J48 decision tree algorithm, and Naïve Bayes classification algorithm were implemented to predict the performance of the students in mathematics in the modern world (MMW). This study employed a correlational and predictive research design where secondary data from the records of the teachers in MMW during the academic year 2019-2020 was used. The data are records of 144 education students which are composed of their ratings in attendance, quizzes, recitation, midterm exam, final exam, and their final grade. Results revealed that the majority of the students performed well in the subject having a very good rating. Also, the analysis revealed that ratings in attendance, quizzes, recitation, midterm exam, and final exam have a significant positive relationship with the final grades. Among the five variables, the most influential component to the overall performance of the students is the midterm exam rating. Using the 10-fold cross-validation, prediction models were also generated using Naïve Bayes and J48. Further, the Naïve Bayes algorithm provides better performance for predicting the students' academic performance in MMW which provided a 73.61% accuracy, followed by the J48 (72.22%), and Multiple Linear Regression with 70.2% accuracy. Lastly, these machine learning models should be employed to improve the learning outcomes of students.

Keywords: *Academic performance, J48 algorithm, Mathematics in the modern world, Multiple linear regression, Naïve Bayes*

Introduction

The recent paradigm shift of education on the new K to 12 curricula in basic education inevitably impacted higher education in the Philippines (De Guzman, 2003). K to 12 makes it necessary to adjust the college curriculum, to make sure that college subjects build upon it in the best way. Part of this is the substantial reduction of the general education (GE) units from the existing 63 units to only 36 GE units (CHED, 2015). This new general education curriculum is anchored on eight courses, which include Mathematics in the Modern World (MMW) (Valencia, 2015; Verdeflor Pacadaljen,

2021). MMW deals with the nature of mathematics, appreciation of its practical, intellectual, and aesthetic dimensions, and application of mathematical tools in daily life (Mathematics in the Modern World Preliminaries [CHED], 2013). This course is expected to provide students with opportunities on solving problems that allow them to understand and value the applicability of Math in various fields and human endeavors (DLSU, 2015). However, previous studies asserted that students are having difficulties with the course that lead them to perform low (Roman & Villanueva, 2020).

Various strategies have been utilized to enhance the performance of the students in mathematics such as the use of culturally specific pedagogy (Leonard, 2018), self-regulated learning (Sun, Xei, & Anderman, 2018), intervention-based active-learning strategies (Enrique & Cusipag, 2020; Sidhu & Srinivasan, 2018), and the use of information and communication technologies (ICT) (Hillmayr et al., 2020; Sharp & Hamil, 2018; Bray & Tangney, 2017). The utilization of ICT to improve the performance of the students in mathematics proved to be effective based on previous studies (Alcantara et al., 2020; Gómez-García et al, 2020; Diaz & Cano, 2019; Hu et al., 2018). ICT has been also used to predict the performance of students in mathematics, particularly, using machine learning algorithms.

The application of machine learning algorithms to predict the academic performance of students has proved to be a beneficial tool for foreseeing poor and good performance in various levels of education (Ofori, Maina, & Gitonga, 2020). Early prediction of the students' academic performance is useful in taking early action of improving learning outcomes. According to Las Johansen and Trecene (2018), predicting academic performance is vital as it is used by academic institutions for strategic planning to improve and maintain the quality of education. Badugu and Rachakatla (2020) stated that the student's academic performance can be measured through learning assessment and co-curriculum activities. They also mentioned that previous performances, grades, and achievements are crucial in predicting the academic success of students (Badgu & Rachakatla, 2020). Furthermore, the grades of the students were commonly used as the basis for the assessment, particularly in higher education (Larrabee Sønderlund, Hughes, & Smith, 2019). In addition, attendance, quiz scores, assignment scores, and final exam scores will affect the student's academic performance (Shahiri & Husain, 2015; Gbollie & Keamu, 2017; Hellas et al., 2018).

In the study of Vamshidharreddy, Saketh, and Gnanajeyaraman (2020), they used a decision tree, support vector machine (SVM), and Naïve Bayes algorithms to predict the performance of the students. Results showed that the Naïve Bayes algorithm provided the best result of 77.0% in terms of the accuracy of the prediction model, followed by a decision tree with 71.0% accuracy, and SVM with 38.0% accuracy. On the other note, Dhilipan et al. (2021) also implemented various algorithms such as binomial logical regression, decision tree, entropy, and K-NN to predict the performance of the students in which the binomial logical regression produced an accuracy of 97.05%, entropy of 91.19%, K-NN with 93.71%, while decision tree model has an accuracy of 88.23%. Jayaprakash, Balamurugan, and Chandar (2018) also conducted a study to predict the academic performance of the students using Naïve Bayes. Results of their study revealed that Naïve Bayes gives high accuracy of 92.2%. Although their study proves that Naïve Bayes is an accurate machine learning model in predicting the performance of students, other machine learning models in predicting students' performance were not tested and evaluated. In the study of Obsie and Adem (2018), various machine learning algorithms were employed to predict the performance of the students in school. These are, Neural Network, Linear Regression (LR), and Support Vector Regression (SVR), where LR and SVR provide the higher accuracy of both 98.05%. However, other models such as decision trees, and other classification algorithms were not tested to evaluate and compare the results. Moreover, Remo (2019), also studied predicting the performance of the students in MMW, regression analysis was used to predict the performance using the high school general average (GPA), admission test scores, and mathematics achievement score. The study

claimed that the high school GPA and admission test scores do not significantly contribute to their performance in mathematics in college.

Based on the works of the literature, machine learning algorithms are widely used in predicting the academic performance of students, these machine learning models produced a good accuracy result. Furthermore, there are limited empirical studies conducted on predicting the performance of students in mathematics in the modern world. The previous study (Remo, 2019) in predicting the performance of students in MMW used only the high school GPA, admission test scores, and mathematics achievement. This study will focus on the actual performance scores of the students in MMW to create a model to predict the future performance of the students. Also, various machine learning algorithms will be implemented to evaluate the best model in predicting the performance of students in MMW.

The purpose of this study is to predict the performance of students in mathematics in the modern world using different machine learning algorithms. In this study, multiple linear regression, J48 decision tree algorithm, and Naïve Bayes classification algorithm were implemented to predict the performance of the students in mathematics in the modern world. Moreover, this research also evaluated and compared the performance of the machine learning algorithms used.

Objectives of the study

This study aimed to predict the performance of the students in mathematics in the modern world using machine learning algorithms such as multiple linear regression, J48 algorithm, and Naïve Bayes algorithm. Specifically, this study aimed to (1) determine the level of academic performance of students in MMW, (2) determine the variables that significantly predict their performance in MMW, (3) model the performance of students in MMW using the J48 decision tree algorithm and Naïve Bayes, and (4) compare the accuracy of the models of multiple linear regression, J48, and Naïve Bayes.

Methodology

Research Design

The study used a correlational and predictive research design which was concerned with forecasting (predicting) outcomes, consequences, costs, or effects (Wollman, Lauren). This design was used since the researcher gathered existing data which includes the ratings in attendance, quizzes, recitation, midterm exam, and a final exam which is the independent variable to predict the academic performance of the students which is the dependent variable.

Dataset

This research used secondary data from the records of the teachers who handled the subject MMW last academic year 2019-2020. The data are records of 144 education students which are composed of their attendance grade, quiz rating, recitation rating, midterm exam rating, final exam rating, and their final grade in the subject.

Table 1. Variables used in the prediction model including its description and domain.

Variable	Description	Domain
Att_R	Attendance Rating of the students	{E, S, VG, G, P, CF, F}
Q_R	Quiz Rating of the students	{E, S, VG, G, P, CF, F}
Rec	Grade of the students in their recitation	{E, S, VG, G, P, CF, F}
M_Exam	Grade of the students in their midterm exam	{E, S, VG, G, P, CF, F}
F_Exam	Grade of the students in their final exam	{E, S, VG, G, P, CF, F}
F-Grade	The final grade of the students in MMW – Class classifier	{E, S, VG, G, P, CF, F}

Ethical consideration

Before the conduct of the study, written permissions were sent to the head of the school where the study was conducted. Likewise, written permissions were sent to the subject teachers handling Mathematics in the Modern World. The study objectives were clearly

explained to the teachers. Measures were undertaken to ensure that all were, in any way not harmed along with the conduct of the study. All derived information was dealt with, with the utmost confidentiality and was solely used for the study.

Data analysis

This study used the frequency counts and percentage to determine the percent distribution of the students' records according to their poperformance in MMW. Also, the multiple linear regression analysis methods were used to investigate the influence and the predictive power of the students' rating on attendance, quizzes, recitation, midterm exam, and their final exam in predicting their performance in MMW.

Multiple linear regression is a statistical technique that uses several exploratory variables to predict the outcome of a response variable (Gunst & Mason, 2018). The goal of multiple linear regression (MLR) is to model the linear relationship between the explanatory (independent) variables and response (dependent) variables (Maulud & Abdulazeez, 2020). It is computed using the formula (1).

$$\hat{y}_j = b_0 + b_1 x_{1j} + b_2 x_{2j} + \cdots + b_p x_{pj} \qquad (1)$$

For the other predictive model development, this study utilized the J48 and Naïve Bayes algorithms and implemented them in Waikato Environment for Knowledge Analysis (WEKA). WEKA is open-source software that consists of a collection of machine learning algorithms for data mining tasks (Kumar et al., 2019). J48 is an open-source Java implementation of a simple C4.5 decision tree algorithm in the WEKA software (Farhad & Sanjay, 2017; Kumar et al., 2019). J48 is an extension of the ID3 classification algorithm, however, there are additional features of J48 such as accounting missing values, decision tree pruning, continuous attribute value change, derivation of rules, etc. Being a decision tree classifier J48 uses a predictive machine-learning model which calculates the resultant value of a new sample-based on various attribute values of the available data. The internal nodes of a decision tree denote the different attributes; the branches between the nodes tell us the possible values that these attributes can have in the observed samples, while the terminal nodes tell us the final value (classification) of the dependent variable (Farhad & Sanjay, 2017). The attribute with the highest information gain will be the root node of the tree and computed using the following formula (1)(2).

$$E(S) = \sum_{i=1}^{n} -Pr(C_i) * log_2 Pr(C_i) \qquad (1)$$

$$G(S, A) = E(S) - \sum_{i=1}^{m} Pr(A_i) E(S_{A_i}) \qquad (2)$$

Likewise, the Naïve Bayes algorithm is an intuitive method that uses the conditional probabilities of each attribute belonging to each class to make a prediction. It uses Bayes' Theorem, a formula that calculates a probability by counting the frequency of values and combinations of values in the historical data. Parameter estimation for Naïve Bayes models uses the method of maximum likelihood. Despite over-simplified assumptions, it often performs better in many complex real-world situations (Farhad & Sanjay, 2017). The formula is presented below (4).

$$P(C_i | x_1, x_2 \ldots, x_n) = \left(\prod_{j=1}^{j=n} P(x_j | C_i) \right) \cdot \frac{P(C_i)}{P(x_1, x_2 \ldots, x_n)} \quad for\ 1 < i < k \qquad (4)$$

Result and discussion

Level of the academic performance of students in MMW

Table 2. Level of academic performance of the students in mathematics in the modern world

Rating Range	Frequency	Percentage	Qualitative Description
1.0-1.4	8	5.56	Excellent
1.5-1.9	52	36.11	Superior
2.0-2.4	74	51.39	Very Good
2.5-2.9	10	6.94	Good
Total	**144**	**100**	

Note: M = 2.01; SD = 0.33; & CV =16.53 %

Table 2 shows that the majority (51.39) of the students performed well in the subject considering that they acquired grades between 2.0 – 2.4 interpreted as "Very Good". Meanwhile, 36.11 percent are superior, and

6.94% are good, while few are excellent with 5.56% of students.

Table 3. Influence of students' ratings per course grade components on their overall performance in mathematics in the modern world

Variable	B	Std. Error	Beta	t-value	p-value
Attendance	0.097	0.041	0.146	2.352	0.020
Quizzes	0.077	0.043	0.113	1.801	0.044
Recitation	0.170	0.049	0.187	3.499	0.001
Midterm Exam	0.338	0.029	0.625	11.479	0.000
Final Exam	0.075	0.026	0.166	2.865	0.005

Note: R = 0.838; R^2 = 0.702; std. Error = 0.692; F = 65.164, p<0.001; Constant = 0.443
Dependent Variable: Grades in Mathematics in the Modern World

The analysis revealed that ratings in attendance, quizzes, recitation, midterm exam, and final exam has a significant positive relationship with the grades or the overall performance of the students with 0.097, 0.077, 0.170, 0.338, and 0.075 B values and p-values of 0.020, 0.044, 0.001, 0.000, and 0.005. Among the five variables, the most influential component to the overall performance of the students is the midterm exam rating. The results in attendance, quizzes, recitation, midterm examination, and final examination account for 70.2 % of the variance in grades, F = 65.164, p<0.001.

J48 decision tree model

Table 4. Generated patterns based on the result of the J48 algorithm.

J48 Decision tree patterns

```
M_Exam = E
|   Att_R = E: E
|   Att_R = S: S
|   Att_R = VG: S
|   Att_R = G: S
|   Att_R = P: S
M_Exam = G: VG
M_Exam = S
|   Att_R = E: S
|   Att_R = S: S
|   Att_R = VG: VG
|   Att_R = G: G
|   Att_R = P: S
M_Exam = VG
|   Att_R = E: S
|   Att_R = S: VG
|   Att_R = VG: VG
|   Att_R = G: VG
|   Att_R = P: VG
M_Exam = F: VG
M_Exam = P: VG
```

Note: *1.0 – 1.4 – Excellent, 1.5 – 1.9 – Superior, 2.0 – 2.4 – Very good, 2.5 – 2.9 – Good, 3.0 – Passed, 3.0 below - Failed*
***M_Exam – Midterm Exam; Att_R – Attendance Rating*

Using the 10-fold cross-validation, the result in table 4 indicates the generated patterns based on the result of the J48 algorithm. The results show that performance in the midterm examination is the most influential factor among grade components in predicting the overall performance in Mathematics in the Modern World. For instance, in the result, if the midterm examination performance is excellent and the attendance rating is excellent, then the overall performance in the course mathematics in the modern world is excellent (M_Exam=E_Att_R=E: E).

Further, the model explains a 72.22% accuracy of those correctly classified instances. Cohen's Kappa statistics are moderately high for the prediction of the overall performance in MMW (CK = 0.49). A value of Cohen's Kappa above 0.40 indicates a reliable model (Landis & Koch, 1977). Hence, the model in predicting the performance in Mathematics in the Modern World is reliable. Figure 1 shows the decision tree generated model.

Evaluation of the models

Table 5. Confusion matrix of J48 model

a	b	c	d	Classified as
3	4	1	0	a = E
0	37	15	0	b = S
0	9	65	0	c = VG
0	2	8	0	d = G

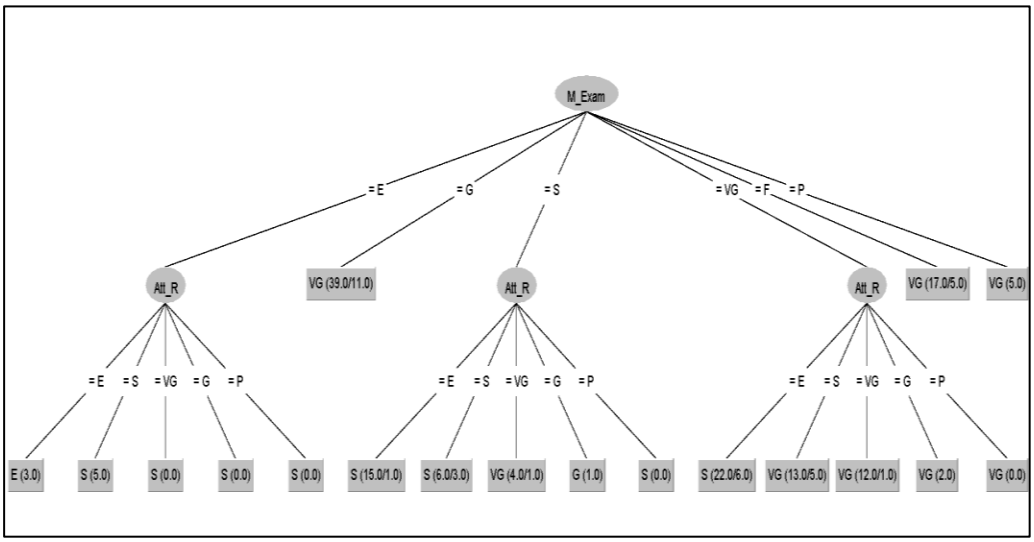

Figure 1 Decision tree model generated using J48 algorithm

Table 6. Confusion matrix of Naïve Bayes model

a	b	c	d	Classified as
4	4	0	0	a = E
2	42	8	0	b = S
0	13	59	2	c = VG
0	1	8	1	d = G

Table 7. Accuracy of the models in predicting the performance of students in MMW using machine learning algorithms

Algorithm	Accuracy
Multiple Linear Regression	70.2%
J48 Algorithm	72.22%
Naïve Bayes	73.61%

Table 7 presents the accuracy of the models generated using the three machine learning algorithms. Multiple linear regression provides 70.2% accuracy, the J48 algorithm gives a 72.22%, while the Naïve Bayes classification algorithm provides a 73.61% accuracy. Among the three algorithms, Naïve Bayes gives the best result. This is similar to the study of Vamshidharreddy, Saketh, and Gnanajeyaraman (2020) where the Naïve Bayes algorithm provides the best accuracy of the model in predicting the academic performance of the students. Compared to the other algorithms used in their study, the Naïve Bayes gives a 77.0% accuracy, while the decision tree (J48) provides 71.0% accuracy. Also, Naïve Bayes had a higher performance with 95.7% in predicting student performance when compared to Support Vector Machine and multi-layer perception network (Belachew & Gobena, 2017).

The result of the present study also supported the study of Jayaprakash, Balamurugan, and Chandar (2018) as cited by Ofori, Maina, and Gitonga (2020) that the Naïve Bayes algorithm predicts students' performance with 92.2% prediction accuracy. Based on the result of their study, Naïve Bayes gave a better prediction result. The previous studies show that the application of educational data mining in analyzing the performance of students using machine learning algorithms is vital in the decision-making process by the authorities in an educational institution. It provides to the institution to identify those students with low performance and formulate measures to improve their performance (Ofori, Maina & Gitonga, 2020; Cornillez Jr, Treceñe & de los Santos, 2020).

Conclusion and recommendations

Predicting the academic performance of students plays an important role in the decision-making process of the academic institution especially in universities. This study analyzed the academic performance of students in Mathematics in the Modern World using various

machine learning algorithms. In this paper, multiple linear regression, J48 decision tree, and Naïve Bayes algorithms were used to predict students' academic performance. The Naïve Bayes algorithm provides better performance for predicting the students' academic performance in MMW.

Although students performed well in MMW, teachers should continue improving their instruction and applying various teaching strategies that will improve the performance of the students, particularly in MMW. Moreover, these machine learning models should be employed to improve the learning outcomes of students. The results of the machine learning models that accurately predict students' performance and include other factors that affect students' performance warrant further investigation..

Acknowledgement

The authors would like to thank the Eastern Visayas State University – Tanauan Campus for allowing them to conduct the study. Also, to the teachers who participated and let the them utilize their available data.

Decleration of no conflict of interest

The Authors declare that there is no conflict of interest.

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How to cite:
Morilla, R. C., Omabe, R. D., Tolibas, C. J. S., Cornillez, Jr., E. E. C., Treceñe, J. K. D. (2020). Application of machine learning algorithms in predicting the performance of students in mathematics in the modern world. *TARAN-AWAN Journal of Educational Research and Technology Management,* 1(1), 49-57.