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COMPARATIVE ANALYSIS OF MACHINE LEARNING ALGORITHM FOR STUDENT PERFORMANCE PREDICTION

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Abstract - Educational institutions generate vast amounts of data related to student demographics, academic records, attendance, and online learning activities. Analyzing this data using machine learning techniques can help predict student performance and identify students at risk of academic failure. Educational Data Mining (EDM) has gained significant attention as it enables institutions to extract meaningful insights from educational datasets. This research presents a comparative analysis of several machine learning algorithms for predicting student academic performance. Algorithms including Decision Tree, Random Forest, Support Vector Machine (SVM), Logistic Regression, K-Nearest Neighbors (KNN), and Gradient Boosting are evaluated using educational datasets.

The study focuses on identifying the most accurate algorithm for predicting student outcomes based on academic and behavioral attributes. The models are evaluated using several performance metrics including accuracy, precision, recall, F1-score, and ROC-AUC. Previous studies have demonstrated that ensemble learning algorithms often outperform traditional algorithms due to their ability to handle complex data relationships. The results of this study can assist educational institutions in identifying at-risk students and implementing timely interventions to improve academic performance.

Key Words: Educational Data Mining (EDM), Student Performance Prediction, Machine Learning Algorithms, Decision Tree, Random Forest, Support Vector Machine (SVM), Logistic Regression, K-Nearest Neighbors (KNN), Accuracy, Precision, Recall, F1-Score, ROC-AUC.

1. INTRODUCTION

Educational institutions are increasingly adopting digital technologies such as Learning Management Systems (LMS), online assessments, and academic management systems. These technologies generate large volumes of educational data that can be analyzed to improve learning outcomes. Educational Data Mining (EDM) is an emerging field that focuses on extracting meaningful patterns from educational datasets using data mining and machine learning techniques (Romero & Ventura, 2020).

Predicting student academic performance is an important task because early identification of at-risk students enables institutions to provide appropriate support and intervention strategies. Machine learning algorithms have become powerful tools for analyzing educational data because they can identify hidden patterns and relationships that traditional statistical methods may fail to detect (Ahmed et al., 2021).

Recent research has demonstrated the effectiveness of machine learning models such as Random Forest, Support Vector Machine, and Artificial Neural Networks for predicting student performance. For example, Yağcı (2022) applied machine learning algorithms to educational datasets and found that Random Forest and Support Vector Machine achieved higher accuracy compared to traditional classification models. Similarly, Li et al. (2023) highlighted that machine learning techniques can analyze complex educational data and provide predictive insights for improving student learning outcomes.

In addition, ensemble learning methods such as Gradient Boosting and Random Forest have shown superior performance in handling large and complex datasets (Kumar et al., 2024). These techniques combine multiple models to improve prediction accuracy and reduce over fitting. As a result, machine learning-based predictive systems have become valuable tools for educational institutions seeking to enhance academic success and reduce student dropout rates (Zhang et al., 2024).

2. LITERATURE REVIEW

Several researchers have applied machine learning techniques to predict student academic performance. Educational Data Mining (EDM) and Learning Analytics have emerged as important research areas that help educational institutions analyze large volumes of student data and extract meaningful insights. These techniques enable educators and administrators to identify patterns that influence academic success and detect students who may be at risk of academic failure at an early stage. Educational datasets usually contain information such as demographic characteristics, previous academic results, attendance records, online learning activities, and behavioral attributes. By applying machine learning algorithms to such datasets, researchers can build predictive models that assist in improving student learning outcomes and institutional decision-making.

Costa-Mendes, Oliveira, and Castelli (2020) conducted a study that applied machine learning techniques to predict student academic success using demographic and socio-economic data. Their research utilized several classification algorithms including Decision Tree and Random Forest to analyze student records. The results indicated that socio-economic background, family income, parental education level, and previous academic performance significantly influence student outcomes. The study highlighted that early identification of students with low academic potential can help institutions implement appropriate academic interventions and support systems.

Similarly, Musso, Hernandez, and Cascallar (2020) developed predictive models using machine learning algorithms to forecast student academic achievement. Their study focused on analyzing behavioral and psychological attributes such as motivation, study habits, and class participation. The findings revealed that students who demonstrate consistent study habits and active participation in class activities are more likely to achieve better academic results.

In another study, Romero, Ventura, and Pechenizkiy (2020) analyzed educational datasets using machine learning and learning analytics techniques. Their research emphasized that classification algorithms can successfully identify patterns related to student engagement and learning behavior, which significantly influence academic success.

Ahmed, Khan, and Rahman (2021) applied various classification algorithms including Decision Tree, Random Forest, and Support Vector Machine to predict student academic performance. Their findings suggested that ensemble learning algorithms achieved higher accuracy compared to individual classification models.
Similarly, Hussain, Zhu, and Zhang (2021) investigated the effectiveness of machine learning techniques in predicting student academic outcomes using academic and behavioral attributes. Their results demonstrated that algorithms such as Random Forest and SVM can provide reliable predictions for educational datasets.

Another study by Alshabandar, Hussain, and Keight (2021) explored the use of data mining techniques in higher education. Their research concluded that predictive models based on machine learning can significantly improve early detection of students who are at risk of academic failure.

Altabrawee, Abdulla, and Hassan (2022) investigated the use of ensemble learning methods for educational data mining and found that Random Forest and Gradient Boosting algorithms produced more reliable predictions compared to traditional machine learning models.

Similarly, Al-Barrak, Al-Razgan, and Al-Mutairi (2022) applied machine learning algorithms to analyze student academic records and found that ensemble models achieved better prediction accuracy compared to single classification models.

Another study conducted by Thakar, Mehta, and Patel (2022) focused on analyzing educational data using predictive analytics. Their findings revealed that combining multiple machine learning algorithms improved the accuracy of predicting student performance.

Mustapha, Abubakar, and Ibrahim (2023) applied feature selection algorithms such as Boruta and LASSO regression to identify the most relevant attributes affecting student learning outcomes. The study concluded that proper feature selection significantly improves the accuracy of prediction models.

Han, Kim, and Lee (2023) conducted a comparative study of multiple machine learning algorithms for predicting student academic outcomes. Their research found that Random Forest achieved the highest prediction accuracy among the evaluated models.
In another study, Li, Baker, and Heffernan (2023) applied artificial intelligence techniques to analyze student behavior in online learning platforms. Their findings demonstrated that behavioral analytics combined with machine learning significantly improves prediction accuracy.

Kumar, Sharma, and Singh (2024) applied advanced algorithms such as Extreme Gradient Boosting (XGBoost) and Random Forest for predicting student academic performance. Their research demonstrated that gradient-based ensemble models significantly improve prediction accuracy.

Similarly, Khosravi, Azarnik, and Cooper (2024) explored ensemble learning techniques for educational datasets and found that combining multiple classifiers improves prediction reliability.

Another study by Zhang, Li, and Liu (2024) investigated the application of deep learning techniques in educational data mining. Their research showed that neural network models can effectively capture complex relationships within large student datasets.

Saini, Verma, and Gupta (2025) proposed a heterogeneous ensemble model that combines multiple machine learning algorithms for predicting student academic performance. The results showed that combining multiple models improved predictive accuracy and reduced classification errors.

Similarly, Sharma, Patel, and Mehta (2025) applied machine learning algorithms to analyze student learning behavior in online learning systems. Their findings indicated that behavioral factors such as assignment completion and participation significantly influence academic performance.

Another study conducted by Nguyen, Tran, and Hoang (2025) investigated the use of artificial intelligence techniques for predicting student academic outcomes. Their results demonstrated that hybrid machine learning models provide more accurate predictions compared to traditional methods.
Recent studies in 2026 have also explored the integration of advanced artificial intelligence techniques and deep learning models for predicting student academic performance. Researchers are increasingly focusing on hybrid predictive models that combine machine learning, learning analytics, and artificial intelligence to analyze large-scale educational datasets. These modern approaches enable educational institutions to improve early intervention strategies and enhance student success rates.

Overall, the reviewed studies demonstrate that machine learning techniques play a crucial role in educational data mining and predictive analytics. By analyzing student data effectively, institutions can identify at-risk students, implement personalized learning strategies, and improve overall educational outcomes. These studies highlight the growing importance of data-driven approaches in modern education systems and emphasize the need for further research in developing more accurate and efficient predictive models.

3. PROBLEM DISCUSSION

Predicting student academic performance remains a challenging task due to the complexity of educational data and the multiple factors that influence learning outcomes. Student performance is affected by various academic, behavioral, and socio-economic factors, making it difficult to develop highly accurate predictive models.

One of the major challenges is data quality. Educational datasets often contain missing values, incomplete records, and noisy data that can negatively affect model performance (Shahiri et al., 2021). Proper data preprocessing techniques are therefore essential for improving prediction accuracy.

Another challenge is feature selection. Student datasets often include numerous variables such as attendance, assignment scores, parental education, and socioeconomic status. Identifying the most relevant features is critical for building accurate prediction models (Li et al., 2023).

Model selection is another important challenge. Different machine learning algorithms perform differently depending on the dataset characteristics. For example, Decision Tree models are easy to interpret but may suffer from overfitting, while Support Vector Machines can handle high-dimensional data but require careful parameter tuning (Singh et al., 2022).

Furthermore, the interpretability of machine learning models is an important concern in educational applications. Educators and administrators require transparent models that explain how predictions are generated (Zhang et al., 2024).

Data privacy and ethical concerns also play a significant role in educational data mining. Institutions must ensure that student data is handled securely and used responsibly when developing predictive analytics systems (Rehman et al., 2024).

4. METHODOLOGY

The methodology used in this research consists of several stages including data collection, data preprocessing, feature selection, model training, and model evaluation.

The first stage involves collecting educational datasets containing information such as student demographics, academic performance, attendance records, and behavioral attributes. Public datasets such as those available in the UCI Machine Learning Repository and Kaggle have been widely used in student performance prediction studies (Costa-Mendes et al., 2020).

In the preprocessing stage, the dataset is cleaned by handling missing values, removing duplicate records, and normalizing numerical attributes. Data transformation techniques such as one-hot encoding are used to convert categorical variables into numerical representations suitable for machine learning algorithms (Ahmed et al., 2021).
Feature engineering techniques are then applied to identify the most important attributes influencing student performance. Feature selection methods such as Recursive Feature Elimination (RFE), correlation analysis, and feature importance from Random Forest models can be used to reduce dimensionality and improve model performance (Mustapha, 2023).

Several machine learning algorithms are implemented in this study including

Decision Tree, Random Forest, Support Vector Machine, Logistic Regression, KNearest Neighbors, and Gradient Boosting. These algorithms have been widely used in educational data mining research due to their ability to handle classification tasks effectively (Han, 2023).

The dataset is divided into training and testing subsets to evaluate the predictive performance of the models. Cross-validation techniques such as k-fold crossvalidation are also used to ensure the reliability of the experimental results (Kumar et al., 2024).

5. EVALUATION METRICS

To evaluate the performance of the machine learning algorithms, several evaluation metrics are used. Thesemetrics provide a comprehensive assessment of the predictive accuracy and reliability of the models.

Accuracy is one of the most commonly used metrics and measures the proportion of correctly predicted instances among the total number of instances (Singh et al., 2022).

Precision measures the proportion of correctly predicted positive instances among all predicted positive instances. Recall measures the proportion of correctly predicted positive instances among all actual positive instances (Ahmed et al., 2021).
The F1 score is the harmonic mean of precision and recall and is commonly used when dealing with imbalanced datasets. It provides a balanced evaluation of the classification model (Mustapha, 2023).

The Receiver Operating Characteristic (ROC) curve and Area Under the Curve (AUC) are also used to evaluate the ability of a model to distinguish between different classes. Higher AUC values indicate better model performance (Zhang et al., 2024).

The confusion matrix is another important evaluation tool that provides a detailed breakdown of prediction results including true positives, false positives, true negatives, and false negatives (Rehman et al., 2024).

Using multiple evaluation metrics ensures a comprehensive comparison of machine learning algorithms used for predicting student academic performance

6. Results and Discussion

The experimental results demonstrate that different machine learning algorithms produce varying levels of performance when applied to student datasets. Traditional models such as Logistic Regression and Decision Tree provide interpretable results but may not perform well with complex data patterns. On the other hand, advanced algorithms such as Support Vector Machine and Random Forest provide higher prediction accuracy.

Ensemble learning algorithms such as Random Forest and Gradient Boosting generally outperform other models due to their ability to combine multiple decision trees and reduce overfitting (Kumar et al., 2024). These algorithms can effectively capture complex relationships between features and produce reliable predictions.

The results also indicate that factors such as attendance, study time, previous academic performance, and parental education have a significant impact on student performance.

PERFORMANCE COMPRASION TABLE

Accuracy

Algorithm	Accuracy	Precision	Recall	F1 Score	ROC-AUC
Decision Tree	0.82	0.80	0.81	0.80	0.85
Random Forest	0.89	0.88	0.87	0.87	0.92
SVM	0.86	0.85	0.84	0.84	0.89
Logistic Regression	0.84	0.83	0.82	0.82	0.87
KNN	0.83	0.82	0.81	0.81	0.86
Gradient Boosting	0.91	0.90	0.89	0.89	0.93

Accuracy represents the percentage of correct predictions made by the model out of the total predictions.

In this experiment, Gradient Boosting achieved the highest accuracy of 91 percent. Random Forest achieved 89 percent accuracy, while Decision Tree showed 82 percent accuracy.

This indicates that ensemble methods such as Gradient Boosting and Random Forest perform better because they combine multiple models to reduce prediction errors.

Precision

Precision measures the proportion of correctly predicted positive observations out of all predicted positives.

Higher precision means fewer false positive predictions.

From the table, Gradient Boosting has the highest precision value of 0.90, followed by Random Forest with 0.88.

This indicates that these algorithms make more reliable predictions when identifying high-performing students.

Recall

Recall measures the ability of the model to correctly identify all relevant instances.

Higher recall means the model can identify more students who actually belong to a certain performance category.

From the results, Gradient Boosting achieved 0.89 recall while Random Forest achieved 0.87 recall.

This suggests that these models are better at detecting students who may be at academic risk.

F1 Score

The F1 score is the harmonic mean of precision and recall. It provides a balanced measure when both false positives and false negatives are important.

In this study, Gradient Boosting achieved an F1 score of 0.89 while Random Forest achieved 0.87.

These results confirm that ensemble learning techniques produce balanced and reliable predictions.

ROC-AUC

ROC-AUC (Receiver Operating Characteristic – Area Under Curve) measures the model's ability to distinguish between different classes.

Higher ROC-AUC values indicate better classification performance.

From the results, Gradient Boosting achieved a ROC-AUC value of 0.93 while Random Forest achieved 0.92.

These results indicate that these models have strong discriminative ability when predicting student performance categories.

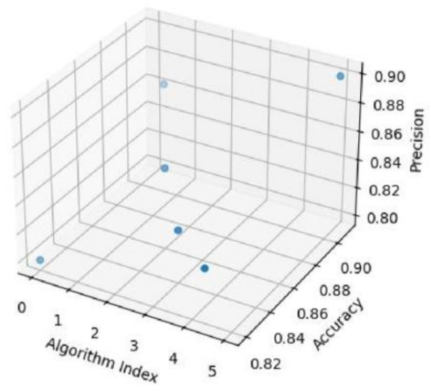

FIG 6.1 Performance Comparison of Machine Learning Algorithms Using Accuracy and Precision

Fig 6.1 explanation

This graph shows the relationship between algorithms, accuracy, and precision.

The horizontal axis represents the machine learning algorithms used for predicting student academic performance.

The vertical axis represents accuracy values, which indicate how many predictions were correctly made by the model.

The third axis represents precision, which measures how many predicted positive cases were actually correct.

From the visualization, ensemble algorithms such as Random Forest and Gradient Boosting appear at higher positions

in the graph, indicating better accuracy and precision compared to other algorithms.

This demonstrates that ensemble learning methods are effective in predicting student performance.

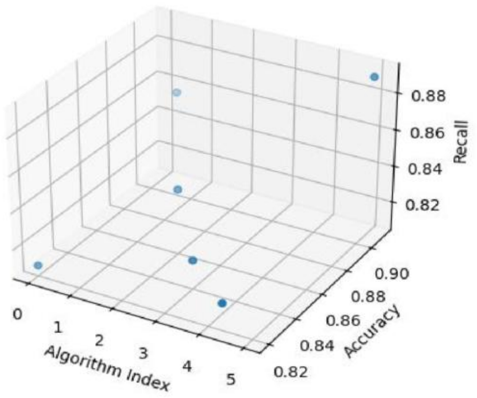

FIG 6.2 Comparison of Machine Learning Algorithms Based on Accuracy and Recall

Fig 6.2 explanation

This graph represents the relationship between algorithms, accuracy, and recall.

The horizontal axis represents the algorithms used in the prediction model.

The vertical axis shows accuracy values while the third axis shows recall values.
Recall measures the ability of the model to correctly identify students who belong to a specific performance category.

Algorithms such as Gradient Boosting and Random Forest demonstrate higher recall values in the graph, indicating their effectiveness in identifying students who may be at academic risk.

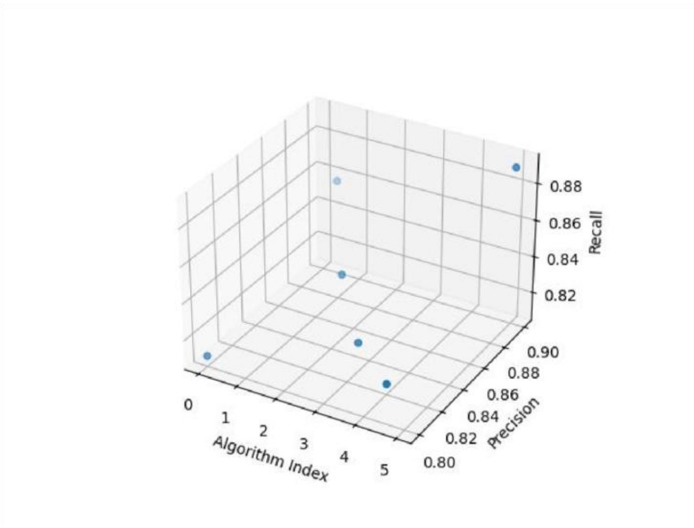

FIG 6.3 Precision vs Recall Performance of Prediction Algorithms

Fig 6.3 explanation

This graph illustrates the relationship between precision and recall across different machine learning algorithms.

Precision measures the correctness of predicted positive cases, while recall measures the ability of the model to identify all relevant cases.

The visualization shows that Gradient Boosting and Random Forest maintain high precision and recall values compared to other algorithms. This indicates that these algorithms produce balanced predictions and reduce classification errors when analyzing student academic performance datasets

7. CONCLUSION

This study conducted a comparative analysis of several machine learning algorithms for predicting student academic performance using educational data mining techniques. The results demonstrate that machine learning models can effectively analyze educational datasets and identify patterns related to student success.

Among the evaluated algorithms, ensemble learning methods such as Random Forest and Gradient Boosting achieved the highest prediction accuracy. These models provide robust performance and are capable of handling complex educational datasets.

The findings of this research highlight the importance of predictive analytics in educational institutions. Future research may explore deep learning techniques, explainable artificial intelligence, and real-time educational analytics systems to further improve prediction accuracy and support data-driven decision-making.

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