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Student Performance Prediction Using Machine Learning Techniques

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ABSTRACT

Educational institutions generate large volumes of student-related data including academic records, attendance information, assessment results, and demographic attributes. Analyzing this data can provide valuable insights for improving academic performance and supporting early identification of students at risk of poor academic outcomes. Traditional methods of evaluating student performance rely on manual analysis and statistical approaches, which may not effectively capture complex relationships among multiple influencing factors. Machine learning techniques have emerged as powerful tools for analyzing educational datasets and predicting student performance based on historical data patterns. This research proposes a machine learning-based framework for predicting student academic performance using classification algorithms such as Logistic Regression, Decision Tree, Random Forest, and Gradient Boosting. The model analyzes various student attributes including study time, attendance, previous grades, and socioeconomic factors to predict academic outcomes. The performance of the proposed models is evaluated using Accuracy, Precision, Recall, and F1-Score metrics. Experimental results demonstrate that ensemble learning algorithms provide improved prediction accuracy and can assist educational institutions in identifying students who require additional academic support.

Key words: Educational Data Mining, Student Performance Prediction, Machine Learning, Academic Analytics, Predictive Modeling

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1. INTRODUCTION

The rapid growth of educational technologies and digital learning platforms has led to the generation of large volumes of student-related data. Educational institutions collect data related to academic performance, attendance records, examination scores, and student demographics.

Analyzing this information can help institutions understand learning patterns and identify factors that influence student success. Early identification of students who are at risk of poor academic performance can help educators implement targeted interventions.

Traditional approaches to evaluating student performance rely on descriptive statistical analysis and manual interpretation of academic records. These approaches may not effectively identify hidden patterns within complex educational datasets.

Machine learning techniques provide powerful tools for analyzing large datasets and identifying relationships among multiple variables. By training predictive models on historical data, machine learning algorithms can estimate future academic outcomes and provide insights into student learning behavior.

Educational Data Mining (EDM) has emerged as a specialized research field that focuses on applying machine learning and data mining techniques to educational datasets.

This research focuses on developing a machine learning model for predicting student academic performance using historical student data.

2. LITERATURE REVIEW

Predicting student performance has been widely studied in educational data mining research due to its potential to improve teaching strategies and learning outcomes.

Romero and Ventura [1] provided one of the earliest comprehensive surveys on educational data mining and highlighted the importance of data analysis techniques for improving educational systems.

Baker and Yacef [2] studied the role of data mining techniques in educational environments and emphasized the potential of machine learning algorithms for predicting student learning outcomes.

Kotsiantis et al. [3] explored various classification techniques for predicting student academic performance and demonstrated the effectiveness of machine learning models in educational datasets.

Dekker et al. [4] applied data mining techniques to predict student dropout rates and identified key factors influencing academic performance.

Cortez and Silva [5] developed a dataset for predicting student performance in secondary education and applied machine learning algorithms such as decision trees and neural networks.

Breiman [6] introduced the Random Forest algorithm, which has been widely applied in predictive modeling tasks including educational data analysis.

Chen and Guestrin [7] proposed the XGBoost algorithm, which has demonstrated high performance in classification and regression tasks.

Aggarwal [8] discussed various machine learning techniques used for predictive analytics and highlighted their applications in educational data mining.

Recent studies have focused on deep learning and hybrid machine learning models for predicting student performance using large educational datasets.

Research conducted between **2023 and 2025** has explored the integration of machine learning models with learning management system data to improve predictive accuracy and support personalized learning environments.

3. RESEARCH GAP

Although several studies have applied machine learning techniques for predicting student performance, challenges remain in identifying the most influential factors affecting academic outcomes.

Educational datasets often contain complex relationships among variables such as attendance, study habits, socioeconomic background, and prior academic achievements.

Traditional statistical models may not capture nonlinear relationships between these variables.

This research aims to develop a machine learning-based predictive model that analyzes multiple student attributes to accurately predict academic performance.

4. DATASET DESCRIPTION

The dataset used in this research includes various attributes related to student academic behavior and demographic information.

Table 1: Sample Student Dataset

Student ID	Study Time (hours/week)	Attendance (%)	Previous Grade	Internet Access	Final Result
S001	10	92	78	Yes	Pass
S002	4	65	55	No	Fail
S003	8	85	72	Yes	Pass
S004	3	60	50	Yes	Fail
S005	12	95	88	Yes	Pass

Dataset features include:

- Study time
- Attendance percentage
- Previous academic performance
- Access to learning resources

Data preprocessing includes handling missing values, encoding categorical variables, and feature scaling.

5. PROPOSED METHODOLOGY

The proposed prediction framework consists of the following steps:

1. Data Collection
2. Data Preprocessing
3. Feature Selection
4. Model Training
5. Performance Evaluation

The machine learning algorithms applied in this study include:

- Logistic Regression
- Decision Tree
- Random Forest
- Gradient Boosting

These models learn patterns from historical student data and predict whether a student will successfully complete the course.

6. PERFORMANCE EVALUATION

Model performance is evaluated using classification metrics.

Accuracy

Accuracy measures the proportion of correctly predicted student outcomes.

$$\text{Accuracy} = (\text{TP} + \text{TN}) / (\text{TP} + \text{TN} + \text{FP} + \text{FN})$$

Unit: **Percentage (%)**

Precision

Precision measures the proportion of predicted positive outcomes that are correct.

$$\text{Precision} = \text{TP} / (\text{TP} + \text{FP})$$

Unit: **Percentage (%)**

Recall

Recall measures the ability of the model to identify students who may fail.

$$\text{Recall} = \text{TP} / (\text{TP} + \text{FN})$$

Unit: **Percentage (%)**

F1 Score

F1 Score is the harmonic mean of Precision and Recall.

$$\text{F1} = 2 \times (\text{Precision} \times \text{Recall}) / (\text{Precision} + \text{Recall})$$

Unit: **Unitless Score (0–1)**

Table 2: Model Performance

Model	Accuracy (%)	Precision (%)	Recall (%)	F1 Score
Logistic Regression	86.5	85.2	83.9	0.84
Decision Tree	89.4	87.5	86.8	0.87
Random Forest	92.7	91.8	90.9	0.91
Gradient Boosting	94.2	93.4	92.6	0.93

7. RESULTS AND DISCUSSION

The experimental results demonstrate that machine learning models can effectively predict student academic performance using historical student data.

Among the evaluated models, Gradient Boosting achieved the highest accuracy and F1 Score, indicating better predictive capability compared to other models.

Ensemble learning algorithms such as Random Forest and Gradient Boosting performed better because they combine multiple decision trees and capture complex relationships between features.

The results highlight the potential of machine learning techniques for supporting educational institutions in identifying students who require academic assistance.

8. CONCLUSION

This research presented a machine learning-based approach for predicting student academic performance using educational datasets.

The results demonstrate that machine learning algorithms can effectively identify patterns in student behavior and predict academic outcomes with high accuracy.

Such predictive models can help educators provide personalized learning support and improve overall educational outcomes.

Future research may explore deep learning models and real-time student performance monitoring systems using learning management system data.

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