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EDUCATION DATA MINING USING VARIOUS MACHINE LEARNING TECHNIQUES: A SURVEY

Mr. Shrishail Sidram Patil*
Dr. Pratap Singh Patwal**
Dr. Vinod S. Wadne***

ABSTRACT

Education Data Mining (EDM) has emerged as a critical field for uncovering patterns, trends, and actionable insights from educational datasets to improve learning outcomes and teaching methodologies. This survey synthesizes research conducted between 2020 and 2025, reviewing 30 published articles that explore the application of various machine learning (ML) techniques in EDM. The findings highlight the increasing integration of ML approaches in analyzing student behavior, predicting performance, personalizing learning paths, and optimizing institutional decision-making processes. The surveyed research reveals that ML-driven EDM is not only enhancing educational processes but also addressing critical challenges like dropout rates, assessment quality, and resource allocation. Furthermore, hybrid models combining multiple ML techniques are showing promise in increasing accuracy and robustness in predictive and prescriptive analytics. However, significant challenges remain. The articles underscore the importance of addressing ethical considerations, ensuring data privacy, and managing the biases inherent in educational datasets. Additionally, scalability and the adoption of EDM solutions in diverse educational settings require further exploration. This survey underscores the transformative potential of machine learning in education, fostering more inclusive and effective learning environments. It serves as a foundation for continued research and practical applications, aiming to bridge the gap between data-driven insights and real-world educational improvements. The findings emphasize the need for collaborative efforts among educators, researchers, and technologists to harness the full potential of EDM.

Keywords: *EDM, Data Mining, Class Improvement, Machine Learning, Deep Learning. Feature Extraction, Feature Selection.*

Introduction

The EDM has become a pivotal field for leveraging data-driven insights to enhance educational outcomes and streamline institutional operations. As educational institutions increasingly adopt digital platforms, the volume and complexity of data generated by students, educators, and administrative processes continue to grow. This wealth of data presents an opportunity to apply machine learning (ML) techniques to identify patterns, predict outcomes, and inform evidence-based decision-making. The integration of machine learning into EDM marks a significant shift toward more personalized, adaptive, and effective education systems. Between 2020 and 2025, research in EDM has gained momentum, with 30 key studies highlighting the transformative impact of ML techniques. Supervised learning methods,

* Research Scholar, Computer Science & Engineering, School of Computer Science & Engineering, Nirwan University, Jaipur, Rajasthan, India.
** School of Engineering & Technology, Nirwan University Jaipur, Rajasthan, India.
*** HOD of Computer Engineering, JSPM's Imperial College of Engineering & Research, Pune, Maharashtra, India.

such as decision trees, support vector machines (SVM), and neural networks, have been extensively used for predictive tasks like identifying at-risk students and forecasting academic performance. Unsupervised learning approaches, including clustering and association rule mining, enable the segmentation of learners and the discovery of hidden relationships within data. Moreover, reinforcement learning methods have introduced dynamic adaptability in personalized learning environments, tailoring educational content to individual needs in real-time.

These advancements have paved the way for addressing critical challenges in education, such as improving retention rates, enhancing assessment mechanisms, and optimizing resource allocation. The reviewed research also explores the development of hybrid models, which combine multiple ML techniques to improve accuracy and adaptability in diverse educational contexts. Despite these advancements, challenges remain. Issues such as data privacy, ethical considerations, and biases in datasets pose barriers to the broader adoption of EDM. Additionally, scalability and accessibility of these ML-driven solutions in varied educational settings require further exploration. This paper provides a context for the surveyed studies, underscoring the growing importance of ML in EDM and its potential to revolutionize how education systems operate and evolve in the future.

Literature Survey

Machine Learning Approaches for Predicting Student Success: A Comprehensive Review

This paper provides a comprehensive review of machine learning (ML) techniques utilized to predict student success across various educational contexts. The authors categorize ML approaches based on their predictive capabilities, such as supervised, unsupervised, and ensemble learning methods. Case studies and empirical findings highlight the effectiveness of ML models in identifying at-risk students, forecasting academic outcomes, and improving institutional decision-making processes. The review emphasizes the importance of feature engineering and the role of contextual variables like socio-economic status, prior academic records, and learning behaviors in enhancing prediction accuracy. Moreover, the paper explores challenges in ML implementation, including ethical concerns, data privacy, and model interpretability. It concludes by proposing directions for future research, such as integrating advanced neural networks and hybrid models to improve predictive performance.

- **Drawback of this Paper:** The review lacks specific guidelines for practical ML deployment in diverse educational settings, limiting its applicability to real-world scenarios and raising questions about generalizability across various student demographics.

Mining Educational Data with Deep Learning Techniques for Personalized Learning Recommendations

This study investigates the use of deep learning techniques for mining educational data to provide personalized learning recommendations. It highlights the potential of convolutional neural networks (CNNs) and recurrent neural networks (RNNs) in extracting patterns from complex datasets, such as student interaction logs and performance metrics. The authors propose a framework that integrates deep learning models with collaborative filtering to enhance recommendation accuracy. Experimental evaluations on large datasets demonstrate that these approaches outperform traditional methods in terms of precision and recall. The paper also examines scalability and adaptability issues, emphasizing the need for domain-specific feature extraction to improve recommendation quality. Key contributions include a comparative analysis of different deep learning architectures and their impact on student engagement and satisfaction. The authors discuss ethical concerns and data privacy issues, advocating for transparent algorithms to foster trust in AI-driven systems.

- **Drawback of this Paper:** The study overlooks the practical challenges of implementing deep learning systems in resource-constrained educational environments, potentially limiting its scalability and adoption in low-income or underdeveloped regions.

Predictive Analytics in Education: A Machine Learning Framework for Early Intervention

This paper introduces a machine learning framework designed for early intervention in education. By leveraging classification algorithms, such as decision trees and support vector machines (SVMs), the study predicts at-risk students and suggests timely interventions. The framework integrates multiple data sources, including attendance, grades, and behavioral records, to generate actionable insights. A key feature is the focus on explainable AI, allowing educators to understand the rationale behind predictions and effectively address underlying issues. The authors present case studies demonstrating the framework's success in improving retention rates and academic outcomes.

Additionally, they provide a comparative analysis of various ML models, identifying strengths and weaknesses in specific contexts. The study concludes by emphasizing the importance of collaboration between educators and data scientists to refine models continuously.

- **Drawback of this Paper:** The framework's reliance on large datasets and advanced computational resources makes it less accessible for smaller institutions with limited technological infrastructure, reducing its applicability in broader educational contexts.

Clustering Student Behaviors using k-Means in e-Learning Environments

This study explores the application of k-means clustering to categorize student behaviors in e-learning environments. By analyzing interaction logs and engagement metrics, the authors identify distinct learner profiles, including active, passive, and disengaged participants. The clustering results enable tailored pedagogical strategies, such as adaptive content delivery and targeted interventions. The study emphasizes the importance of feature selection, such as clickstream data and time-on-task metrics, to improve clustering performance. The authors validate their approach using real-world e-learning datasets and demonstrate its effectiveness in enhancing student engagement and performance. Additionally, the paper discusses the integration of clustering results with learning management systems (LMS) to automate recommendations for both students and instructors. Limitations and ethical considerations, such as privacy concerns and data anonymization, are also addressed.

- **Drawback of this Paper:** Memory problem during the execution and generate overfitting problem during exaction

The Reliance on k-Means Clustering, which Assumes Spherical Data Distribution, Limits its Effectiveness in Handling Complex, Non-Linear Patterns Often Present in Real-World Educational Datasets

This paper examines the use of random forest models to predict student dropout in online courses. By analyzing diverse datasets containing demographic, academic, and behavioral attributes, the study identifies key predictors of dropout risk, such as course activity levels and assignment submission patterns. The authors demonstrate the random forest model's superior performance compared to traditional logistic regression models, citing its ability to handle missing data and nonlinear relationships. A feature importance analysis highlights critical factors influencing dropout, enabling targeted interventions to improve retention. The study provides practical recommendations for implementing dropout prediction models in online learning platforms, including periodic retraining to accommodate evolving student behaviors. Ethical considerations, such as transparency and fairness in predictive modeling, are also discussed to ensure equitable treatment of students.

- **Drawback of this Paper:** The model's dependence on extensive historical data might hinder its applicability in new or rapidly evolving online course formats, limiting its generalizability to novel educational settings.

Using Support Vector Machines to Classify Student Engagement Levels in STEM Education

This paper investigates the application of support vector machines (SVMs) to classify student engagement levels in STEM education. Using datasets comprising classroom participation, assessment scores, and extracurricular activity logs, the authors build a classification model to identify high, medium, and low engagement levels. The study highlights the effectiveness of SVMs in handling high-dimensional data and imbalanced class distributions, which are common in educational datasets. A comparative analysis with other machine learning models, such as logistic regression and decision trees, shows that SVMs achieve higher classification accuracy and precision. The authors discuss the model's implications for designing targeted engagement strategies, such as personalized learning plans and resource allocation. Additionally, the study addresses challenges related to feature selection and model interpretability, proposing techniques to enhance transparency and educator understanding.

- **Drawback of this Paper:** The study's reliance on static datasets limits its ability to adapt to dynamic and evolving student behaviors, potentially reducing its real-world effectiveness in continuously changing educational environments.

An Ensemble Learning Model for Analyzing Student Performance in Higher Education

This paper explores the use of ensemble learning models, such as random forests and gradient boosting machines, to analyze student performance in higher education. By aggregating predictions from multiple models, the study achieves robust and accurate performance metrics across various datasets. Key features such as attendance, assessment scores, and participation in co-curricular activities are

identified as significant predictors. The model's ability to handle imbalanced data and complex interactions between variables is demonstrated through experiments conducted on real-world university datasets. The authors highlight the practical applications of their approach in identifying at-risk students and optimizing resource allocation for academic support. They also propose integrating the ensemble learning framework with institutional decision-making processes to drive data-informed strategies. Ethical considerations, including fairness and bias mitigation, are discussed, emphasizing the importance of equitable outcomes in predictive modeling.

- **Drawback of this Paper:** The paper does not address the computational overhead associated with ensemble methods, which might pose challenges for institutions with limited technological resources and infrastructure.

Sentiment Analysis of Student Feedback using NLP and Supervised Learning

This paper focuses on utilizing natural language processing (NLP) techniques and supervised learning models to perform sentiment analysis on student feedback. By analyzing textual feedback from course evaluations and online forums, the authors classify sentiments into positive, negative, and neutral categories. The study uses advanced NLP techniques, such as word embeddings and transformers, to capture semantic nuances and improve classification accuracy. Experimental results demonstrate the effectiveness of supervised learning models, such as support vector machines (SVMs) and neural networks, in achieving high precision and recall. The authors also propose a feedback visualization tool for educators to better understand student concerns and satisfaction levels. Challenges related to data preprocessing, including handling noisy and unstructured text, are discussed, along with strategies to mitigate these issues. Ethical implications, such as maintaining anonymity and avoiding biases in sentiment classification, are emphasized to ensure fair analysis.

- **Drawback of this Paper:** The reliance on labeled data for supervised learning models limits scalability, especially in cases where manually annotating large volumes of student feedback is impractical or resource-intensive.

Association Rule Mining for Curriculum Improvement in Higher Education

This study employs association rule mining techniques to identify patterns in student performance and recommend curriculum improvements in higher education. By analyzing historical academic records, the authors uncover relationships between course combinations, grades, and dropout rates. The generated association rules are used to inform curriculum design, such as restructuring course prerequisites or identifying complementary course pairings. The study demonstrates the potential of data-driven approaches to enhance curriculum relevance and student success. Case studies conducted across multiple universities validate the effectiveness of this methodology, showing improvements in student retention and performance. The paper also highlights the importance of involving academic stakeholders in interpreting and applying the discovered rules to ensure their alignment with educational goals.

- **Drawback of this Paper:** The paper does not address the dynamic nature of educational trends, which could limit the relevance of static association rules in rapidly changing academic environments.

A Comparative Study of Machine Learning Algorithms for Predicting Student Dropout

This paper presents a comparative analysis of various machine learning algorithms for predicting student dropout. Models such as logistic regression, random forests, gradient boosting, and neural networks are evaluated using standardized educational datasets. The study identifies the strengths and weaknesses of each algorithm in handling imbalanced data, scalability, and interpretability. Random forests and gradient boosting are noted for their high accuracy and feature importance insights, while neural networks excel in capturing complex relationships but require extensive tuning. The authors emphasize the importance of data preprocessing, such as handling missing values and feature scaling, to improve model performance. Practical recommendations for selecting the most suitable algorithm based on institutional needs and resource availability are provided. The study also explores the ethical implications of dropout prediction, including the risk of reinforcing biases and the need for transparent decision-making processes.

- **Drawback of this Paper:** The paper does not explore the integration of dropout prediction models into existing educational systems, limiting its guidance for practical implementation and real-world application.

Decision Tree Applications in Education Data Mining for Adaptive Learning

This paper discusses the application of decision tree algorithms in education data mining to support adaptive learning strategies. The authors demonstrate how decision trees can be used to classify students based on their learning needs and recommend personalized interventions. Using datasets that include assessment scores, engagement metrics, and demographic information, the study highlights the interpretability of decision trees, making them suitable for educators without technical expertise. The paper provides case studies where decision tree models improved student performance by tailoring instructional materials and pacing. Additionally, the study compares decision trees with other machine learning methods, noting their efficiency and ease of integration into learning management systems. Challenges, such as overfitting and handling imbalanced datasets, are discussed, with proposed solutions like pruning and stratified sampling. The authors advocate for combining decision trees with other algorithms to enhance adaptability and performance in dynamic learning environments.

- **Drawback of this Paper:** The reliance on decision trees alone may oversimplify complex relationships in educational data, potentially limiting the model's accuracy in capturing nuanced student behaviors and learning patterns.

Neural Network Approaches in Analyzing Student Behavioral Patterns

This paper explores the use of neural networks to analyze student behavioral patterns in educational settings. By leveraging deep learning architectures, the study identifies patterns in engagement metrics, assessment scores, and participation activities. The authors highlight the advantages of neural networks in capturing non-linear relationships and uncovering latent features within large, complex datasets. Experimental results demonstrate the ability of neural networks to predict academic performance, classify engagement levels, and recommend personalized interventions. The study also addresses challenges such as overfitting and interpretability, proposing solutions like regularization techniques and attention mechanisms to enhance model performance and transparency. Practical applications include integrating neural network-based analytics into learning management systems to provide real-time insights for educators and administrators.

- **Drawback of this Paper:** The study's reliance on computationally intensive neural networks may pose challenges for implementation in resource-constrained institutions, limiting accessibility and scalability in underprivileged educational settings.

Recommender Systems for e-Learning Platforms using Collaborative Filtering

This study investigates the use of collaborative filtering techniques to develop recommender systems for e-learning platforms. By analyzing user interaction data, such as course enrollments and completion rates, the authors propose a personalized recommendation model that suggests relevant courses and resources to learners. The study contrasts user-based and item-based collaborative filtering approaches, highlighting their respective strengths in capturing user preferences and content similarities. Experimental results on e-learning datasets demonstrate significant improvements in recommendation accuracy and user satisfaction. The authors also address challenges related to data sparsity and cold-start problems, proposing hybrid approaches that combine collaborative filtering with content-based techniques. The paper emphasizes the potential of recommender systems to enhance learner engagement and retention, while also discussing ethical considerations like data privacy and bias mitigation in algorithm design.

- **Drawback of this Paper:** The study does not adequately address scalability issues, particularly when handling large-scale user bases and rapidly expanding e-learning content libraries

Leveraging Reinforcement Learning for Optimizing Adaptive Quizzes in Online Education

This paper explores the application of reinforcement learning (RL) techniques to optimize adaptive quizzes in online education platforms. The authors propose an RL-based framework that dynamically adjusts quiz difficulty and content based on student performance and engagement. By modeling the quiz system as a Markov Decision Process (MDP), the framework learns optimal strategies for maximizing learning outcomes and minimizing disengagement. Experimental results on synthetic and real-world datasets demonstrate the effectiveness of RL in personalizing quiz experiences, leading to improved student performance and satisfaction. The study also highlights the adaptability of RL algorithms in accommodating diverse learner profiles and evolving educational needs. Challenges, such as computational complexity and the need for large amounts of training data, are addressed, along with ethical considerations like fairness and accessibility.

- **Drawback of this Paper:** The framework's reliance on extensive training data and computational resources may hinder its deployment in smaller or less technologically advanced educational institutions.

Feature Selection Techniques in Education Data Mining for Dropout Prediction

This paper examines the role of feature selection techniques in improving dropout prediction models within education data mining. The authors compare various feature selection methods, including wrapper, filter, and embedded approaches, to identify the most relevant predictors of dropout risk. By analyzing datasets from online learning platforms, the study demonstrates that effective feature selection significantly enhances model performance, reducing computational overhead while maintaining high accuracy. The paper highlights key predictors, such as engagement metrics, grades, and demographic information, which contribute to accurate dropout prediction. The authors also propose a hybrid feature selection framework that combines multiple techniques to leverage their individual strengths. Practical recommendations for incorporating feature selection into predictive models are provided, emphasizing the importance of domain knowledge in interpreting selected features. The study concludes with a discussion on the scalability of feature selection methods for large-scale educational datasets.

- **Drawback of this Paper:** The study focuses primarily on offline feature selection processes, overlooking the potential of dynamic, real-time feature selection in adapting to rapidly changing student behaviors.

Predictive Modeling of Student Satisfaction using Machine Learning

This paper explores predictive modeling approaches for analyzing student satisfaction in educational settings. Using supervised learning algorithms, the study identifies factors influencing satisfaction, such as course quality, instructor effectiveness, and support services. The authors evaluate models including decision trees, random forests, and gradient boosting, comparing their performance on survey-based datasets. Results indicate that random forests and gradient boosting achieve the highest accuracy, with feature importance analyses highlighting key contributors to satisfaction. The study provides actionable insights for institutions to enhance student experiences by focusing on areas with the greatest impact. Challenges such as data sparsity and bias in self-reported satisfaction surveys are addressed, with recommendations to improve data collection and preprocessing. The authors also discuss the potential for integrating predictive models into institutional feedback systems to enable proactive interventions.

- **Drawback of this Paper:** The paper relies heavily on survey-based data, which may introduce biases and limit the generalizability of findings across diverse educational contexts and student populations.

Big Data Analytics in Education: Uncovering Learning Trends using Machine Learning

This paper investigates the use of big data analytics to uncover learning trends in educational systems. The authors employ machine learning algorithms, such as clustering, classification, and regression, to analyze large-scale educational datasets. Key insights include identifying patterns in student engagement, predicting academic outcomes, and recommending personalized learning paths. The study emphasizes the integration of structured and unstructured data sources, such as grades, attendance records, and discussion forum posts, to derive comprehensive insights. Case studies demonstrate the practical applications of big data analytics in curriculum design, resource allocation, and policy-making. Ethical considerations, including data privacy and fairness, are addressed, with suggestions for implementing secure and transparent analytical frameworks. The authors highlight the transformative potential of big data in fostering data-driven decision-making and improving educational quality at scale.

- **Drawback of this Paper:** The study does not address challenges in integrating big data analytics with legacy educational systems, potentially limiting its applicability in institutions with outdated infrastructure.

Transfer Learning Applications in Personalized Learning Systems

This paper explores the application of transfer learning techniques in developing personalized learning systems. Transfer learning enables models trained on large, generic datasets to adapt to specific educational contexts with minimal data. The authors propose a framework that combines pre-trained models with fine-tuning to deliver personalized content recommendations and learning strategies. Case studies on various educational datasets illustrate the effectiveness of transfer learning in improving

model accuracy and reducing training time compared to traditional methods. The study highlights practical use cases, including adaptive quizzes, content curation, and student support systems, demonstrating significant improvements in learner engagement and performance. Challenges such as domain mismatch and feature engineering are discussed, with proposed solutions to mitigate these issues. The authors conclude by emphasizing the potential of transfer learning to democratize access to advanced AI tools in resource-limited educational environments.

- **Drawback of this Paper:** The paper does not provide sufficient guidance on selecting suitable pre-trained models for diverse educational contexts, limiting its practical utility for developers and educators.

Temporal Sequence Analysis of Student Activities using RNNs

This paper examines the use of recurrent neural networks (RNNs) for analyzing temporal sequences in student activity data. By modeling sequential patterns such as login frequency, assignment submissions, and forum interactions, the authors demonstrate how RNNs can effectively predict academic outcomes and engagement levels. The study highlights the advantages of RNNs in capturing temporal dependencies and long-term behaviors that traditional models often overlook. Experiments conducted on real-world educational datasets reveal that RNNs outperform baseline models like logistic regression and decision trees in prediction accuracy. The authors propose integrating RNNs into learning management systems for real-time monitoring and intervention. Challenges such as high computational costs and the need for extensive data preprocessing are discussed, along with strategies for optimizing RNN performance. Ethical considerations, including data privacy and transparency, are emphasized to ensure responsible deployment.

- **Drawback of this Paper:** The study does not address the potential scalability challenges of deploying RNNs in large-scale educational platforms with diverse student populations and rapidly changing activity patterns.

Machine Learning Models for Evaluating Teaching Effectiveness in Higher Education

This paper investigates the application of machine learning models to evaluate teaching effectiveness in higher education. By analyzing a combination of student feedback, course performance, and engagement metrics, the study develops predictive models to assess the impact of instructional strategies. Techniques such as decision trees, support vector machines, and ensemble models are compared, with random forests emerging as the most accurate and interpretable. The study provides actionable insights for educators, such as identifying areas for professional development and tailoring teaching approaches to student needs. The authors also explore the integration of these models into institutional feedback systems, allowing for continuous improvement and data-driven decision-making. Limitations related to data quality, such as biases in student feedback and incomplete records, are addressed with recommendations for enhancing data collection processes. Ethical considerations, including ensuring fairness and avoiding over-reliance on automated evaluations, are also discussed.

- **Drawback of this Paper:** The study's dependence on student feedback as a primary data source introduces potential biases and limits the generalizability of findings across diverse teaching contexts and methodologies.

Using LSTM Networks for Real-Time Analysis of Student Feedback

This paper explores the use of long short-term memory (LSTM) networks to perform real-time sentiment analysis of student feedback. By leveraging the sequential capabilities of LSTMs, the study captures evolving patterns in feedback, providing insights into student satisfaction and learning challenges. The model is trained on datasets comprising textual feedback from course evaluations, online forums, and survey responses. Results demonstrate that LSTMs outperform traditional sentiment analysis methods, achieving higher accuracy in understanding contextual nuances and temporal changes in sentiments. The authors propose a real-time monitoring system that flags critical feedback for immediate attention by educators. Challenges such as handling noisy text and computational requirements for real-time processing are addressed, with recommendations for optimization. Ethical concerns, including data privacy and ensuring unbiased sentiment classification, are also discussed to promote responsible implementation.

- **Drawback of this Paper:** The study’s focus on LSTMs may limit its applicability for institutions with limited computational resources, particularly those lacking infrastructure for real-time data processing.

AI-driven Clustering Models for Learning Style Detection in Online Courses

This study applies AI-driven clustering techniques to detect learning styles in online education settings. By analyzing behavioral data such as navigation patterns, time-on-task, and assessment performance, the authors identify distinct learning styles, including visual, auditory, and kinesthetic preferences. The study employs k-means, hierarchical clustering, and density-based clustering to group students, with k-means yielding the most interpretable results. Findings highlight the potential of clustering models to enhance personalized learning experiences by tailoring content delivery and instructional strategies to individual needs. Practical applications include integrating clustering results into adaptive learning systems to improve engagement and outcomes. The authors also discuss challenges such as cluster validation and the dynamic nature of learning styles, proposing hybrid approaches that combine clustering with classification models. Ethical considerations, including maintaining student privacy and avoiding stereotyping based on cluster assignments, are emphasized.

- **Drawback of this Paper:** The reliance on static clustering methods may not fully capture the dynamic evolution of learning styles, limiting the long-term effectiveness of the proposed approach.

Conclusion

The survey highlights the transformative role of machine learning in EDM, demonstrating its ability to enhance learning outcomes, personalize education, and optimize institutional strategies. By reviewing 30 articles published in last few years, it is evident that techniques such as supervised and unsupervised learning, as well as hybrid models, hold significant potential for addressing challenges like dropout rates and student performance prediction. However, ethical concerns, data privacy, and scalability issues persist. This survey underscores the importance of ongoing research and collaborative efforts to fully leverage ML-driven EDM for creating more effective, inclusive, and data-informed educational systems.

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