

The logo for RADemics, featuring the text "RADemics" in white on a blue arrow-shaped background pointing to the right. The arrow is part of a larger blue horizontal bar that is itself part of a dark blue vertical bar on the left side of the page.

RADemics

Hybrid ML–Fuzzy Systems for Student Academic Performance Prediction

A decorative graphic consisting of several thin, curved lines in shades of blue and grey, originating from the bottom left and extending upwards and to the right, resembling stylized grass or reeds.

Dinesh V Jamthe, Palabindela Swetha,
Punam pankaj Manwatkar
PRIYADARSHINI BHAGWATI COLLEGE OF
ENGINEERING, VNRVJET,

Hybrid ML–Fuzzy Systems for Student Academic Performance Prediction

¹R. Saraswathy, Academic Director/ Professor, Department of Management, Shrimati Indira Gandhi College, Tiruchirappalli, Tamilnadu. saraswathyr@sigc.edu

²Shaik Balkhis Banu, Assistant Professor, Department of Physiotherapy, Fatima college of health sciences, Al Ain, United Arab Emirates. drshaikbalkhis@gmail.com

Abstract

Rapid expansion of digital learning environments and academic information systems has generated large volumes of educational data that create new opportunities for intelligent academic analytics and data-driven decision making. Accurate prediction of student academic performance plays a crucial role in identifying learning difficulties, supporting early intervention strategies, and improving overall educational outcomes. Conventional machine learning approaches demonstrate strong capability in discovering complex patterns within educational datasets, yet limited interpretability and difficulty in managing uncertain or linguistic educational variables reduce practical effectiveness in academic decision-support environments. Fuzzy logic reasoning provides a complementary analytical framework through linguistic rule representation and the ability to model imprecise educational attributes such as learning engagement, participation intensity, and study consistency. Integration of machine learning techniques with fuzzy inference mechanisms forms hybrid intelligent systems capable of combining predictive accuracy with transparent reasoning. This book chapter presents a comprehensive exploration of hybrid machine learning–fuzzy systems for student academic performance prediction within modern educational analytics frameworks. Fundamental concepts of machine learning and fuzzy reasoning are examined in relation to educational data analysis, followed by discussion of hybrid architectures that integrate fuzzy feature transformation, rule-based inference structures, and machine learning prediction algorithms. Key aspects including educational data sources, feature selection strategies, data preprocessing procedures, model training mechanisms, and validation strategies are examined to support the development of reliable predictive systems. Hybrid ML–fuzzy frameworks enable effective modeling of complex learning behaviors while producing interpretable decision rules that assist educators and academic administrators in monitoring student progress. Early identification of academically at-risk students, enhanced academic monitoring, and improved institutional decision support emerge as important outcomes of hybrid intelligent educational systems. Analytical insights generated through such approaches contribute to the advancement of intelligent learning analytics and strengthen the role of computational intelligence in modern education.

Keywords: Educational Data Mining, Academic Performance Prediction, Hybrid Machine Learning, Fuzzy Logic Systems, Learning Analytics, Intelligent Educational Systems.

Introduction

Rapid growth of digital technologies in education has transformed the manner in which learning activities, academic records, and student interactions are recorded and analyzed [1]. Modern

educational institutions generate extensive volumes of structured and unstructured data through learning management systems, online assessments, digital classrooms, and academic information systems [2]. Such data sources contain valuable information regarding student learning behaviour, course engagement, academic progress, and performance outcomes. Analytical examination of these datasets enables educational researchers and administrators to understand patterns associated with student achievement and academic difficulty [3]. Predictive analytics therefore gains increasing importance within educational environments because accurate prediction of academic performance supports proactive academic planning and informed decision making. Identification of students facing potential learning challenges at an early stage strengthens opportunities for academic guidance and institutional intervention [4]. Intelligent computational techniques capable of analyzing large educational datasets contribute significantly toward achieving these objectives. Development of predictive models based on data-driven approaches therefore receives considerable attention within the field of educational data mining and learning analytics [5].

Academic performance prediction involves the analysis of multiple variables that influence learning outcomes within educational systems. Student success depends on a combination of academic, behavioral, psychological, and environmental factors that interact in complex ways [6]. Variables such as attendance patterns, participation in classroom activities, study discipline, assessment performance, and engagement with digital learning platforms contribute important signals regarding academic progress [7]. Traditional statistical methods such as regression analysis and correlation studies provide initial insights into relationships between these variables. Such approaches often rely on assumptions of linear relationships and clearly defined numerical boundaries among variables [8]. Educational environments, in contrast, involve complex and dynamic interactions among learning factors that rarely follow simple linear patterns [9]. Data generated through modern educational systems contain nonlinear relationships and hidden patterns that require advanced analytical techniques capable of extracting meaningful insights from high-dimensional datasets. Machine learning techniques emerge as powerful tools for addressing this complexity and enabling effective academic prediction within contemporary educational analytics frameworks [10].