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Literature Review

How Machine Learning (ML) is Transforming Higher Education: A Systematic Literature Review

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ABSTRACT

In the last decade, artificial intelligence (AI), machine learning (ML) and learning data analytics have been introduced with great effect in the field of higher education. However, despite the potential benefits for higher education institutions (HIE´s) of these emerging technologies, most of them are still in the early stages of adoption of these technologies. Thus, a systematic literature review (SLR) on the literature published over the last 5 years on potential applications of machine learning in higher education is necessary. Following the PRISMA guidelines, out of the 1887 initially identified SCOPUS-indexed publications on the topic, 171 articles were selected for review. To screen the abstracts and titles of each citation, Rayyan QCRI was used. VOSViewer, a software tool for constructing and visualizing bibliometric networks, and Microsoft Excel were used to generate charts and figures. The findings show that the most widely researched application of ML in higher education is related to the prediction of academic performance and employability of students. The implications will be invaluable for researchers and practitioners to explore how ML and AI technologies ,in the era of ChatGPT, can be used in universities without jeopardizing academic integrity.

Keywords: Artificial Intelligence, Machine Learning, Deep Learning, Learning Analytics, Systematic Literature Review, ChatGPT, Higher Education, Digital Transformation, Industry 4.0.

INTRODUCTION

In the last decade, ML has been successfully implemented in a wide range of industries including medicine, hospitality, finance and e-commerce with profoundly disruptive effects. In this regard, the educational sector is no exception.

According to McKinsey, data science and machine learning have the potential to add value for universities by unlocking significantly deeper insights into their student populations and identifying more nuanced risks than they could achieve through descriptive statistics greatly improving student retention and satisfaction (McKinsey, 2022). In addition, learning analytics could be used across the entire student journey (prospective, current and former students). For example, ML could identify the high schools and areas that tend to produce the best talent for an HIE, help identify what are the best measures to improve student satisfaction and better engage with the alumni by providing them with continual learning opportunities after graduation.

In addition, 2022 marked the release of ChatGPT-3, an AI chatbot fine-tuned using both supervised and reinforcement learning, that garnered extensive media attention for its human-like responses. In response, several authors have expressed concern regarding the risk of ChatGPT being misused to cheat on exams and for plagiarism (Gilson et al., 2023). Thus, to ensure academic integrity, HIE´s will have to fundamentally rethink the way the assess students.

The main aim of this SLR was to evaluate the current state of the art in the use of ML in higher education. To that end, an analysis of a sample of peer-reviewed articles focusing on this topic was performed to ascertain:

- The relevant journals, authors, countries and keywords.
- The main applications of ML in the context of higher education.

Regarding the structure of this article, in the first part, the concept of machine learning will be explored and several literature review studies that have sought to analyze the same topic will be discussed. In the second part, the methodology of this SLR will be explained. After presenting the main results, the main conclusions, limitations and areas for further research will be discussed.

THEORITICAL FRAMEWORK AND RELATED STUDIES

Originally coined in 1959 by Arthur Samuel, the term "Machine Learning" (ML) refers to a form of Artificial Intelligence (AI) that focuses on developing and understanding computer models that "learn" how to leverage data to perform a set of tasks (A. L. Samuel, 1959). Thus, machine learning seeks to mimic how humans acquire new knowledge required to complete certain tasks by studying and modeling them computationally. Deep Learning (DL) is a form of Machine Learning (ML) that employs multiple layers for feature extraction from the raw input and is based on artificial neural networks with representation learning(Deng and Yu, 2014). The distinction between AI, DL and ML was further clarified in **Figure 1**. According to (Bishop and Nasrabadi, 2006), ML and DL approaches can be classified into three distinct learning paradigms:

Supervised learning: Using a representative training set of well-known examples given by a "teacher", the machine first "learns" how to apply a general rule to map further examples (a testing set) for which a certain target property is unavailable and then to unknown examples.

Unsupervised learning: Unlike in supervised learning, the input data is unlabeled, so the machine is left by itself to use just an input dataset to discover hidden patterns in data.

Reinforcement learning: The machine is given no predefined data and is left unsupervised, so it must navigate its way through a certain problem learning by trial-and-error. A computer program interacts with dynamic environment that rewards the computer program when it does a certain task correctly.

In a SLR of 67 studies, (Kučak et al., 2018) proposed a classification of the research on the area of ML applications in education into 4 distinct areas: Grading students; Improving student retention; Predicting student performance and Testing students. Predicting student performance was the area with the highest number of studies which seems to suggest that this is perhaps the most important ML application.

On topic of student performance predictions which includes predicting students grades (tests, exams, quizzes, assignments, GPA) and attendance, (Nawang et al., 2021) analyzed 40 papers and found that this application of ML has been widely adopted in higher education. Regarding the most widely used techniques by researchers, the authors found that while Decision Tree, Random Forest, SVM, Artificial Neural Network (ANN) and Naïve Bayes (NB) were the most widely used techniques and it was Random Forest that proved to be the most accurate technique in predicting student performance.

(Shafiq et al., 2022) conducted a SLR of 100 articles that concluded that supervised ML techniques were the most widely used in predictive models for student retention. The authors presented a more detailed taxonomy of ML approaches and concluded that the most widely used techniques were Random Forest, Normal Decision Tree, Logistic Regression and Naïve Bayes. Python surpassed R as the most widely used programming language in these studies. Regarding the factors that can help determine high-risk students to prevent dropouts, the authors showed that most studies use a combination of several academic, time-related and socio-demographic indicators.

METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework was used to conduct a systematic literature review to analyze, choose and visualize the articles more clearly. PRISMA focuses on ways in which authors can ensure transparent and complete reporting of systematic reviews and meta-analyses (Moher et al., 2014).

The SCOPUS database was used to search for studies in peer-reviewed publications like articles, conference papers and review articles in the final stage of publication. Only articles published between 2019 and 2023 were included. The following search terms were used: (TITLE-ABS-KEY (machine AND learning) OR TITLE-ABS-KEY (ml) AND TITLE-ABS-KEY (education)) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (PUBYEAR , 2023) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019)) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (EXACTKEYWORD , "Machine Learning") AND (LIMIT-TO (OA , "all")).

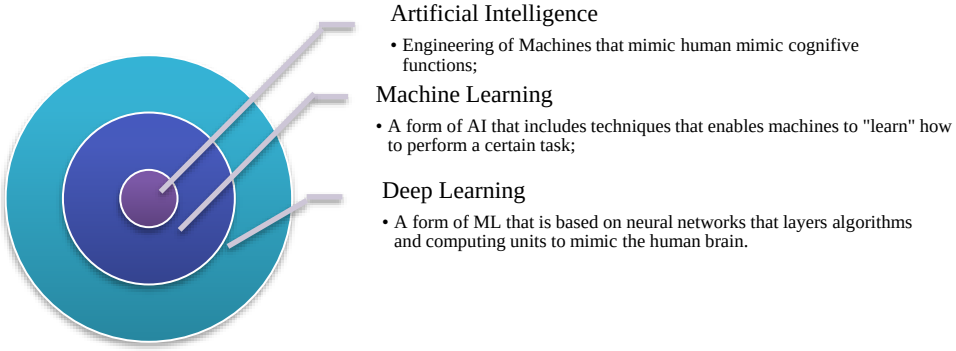

Figure 1. Distinction between AI, Machine Learning and Deep Learning

All duplicates, thesis, dissertations, monographies, books and other non-peer reviewed articles were excluded. Additionally, only articles published written in English that focus on the application of ML in the context of higher education and include the keyword "Machine Learning" were included.

Furthermore, the search results were downloaded from the SCOPUS database to RIS.file that was uploaded to the Rayyan QCRI, a dedicated AI powered online tool for expediting the process of conducting systematic literature reviews. Next, the abstracts and titles of each citation were analyzed using the Rayyan QCRI platform. The next step was exporting the final sample to a RIS. file that could be uploaded to VOSViewer, a software tool for constructing and visualizing bibliometric networks. Using VOSViwer, a co-occurrence analysis was carried out to map out the main keywords. Finally, Microsoft Excel was used to create several charts with the goal of illustrating the data and facilitating the analysis.

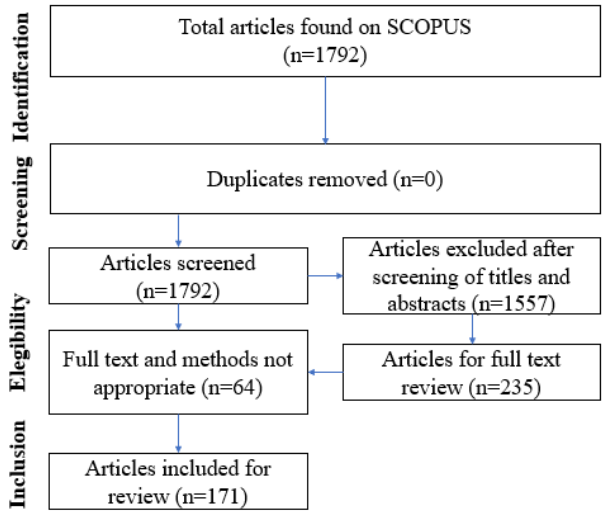

Figure 2. PRISMA Flowchart

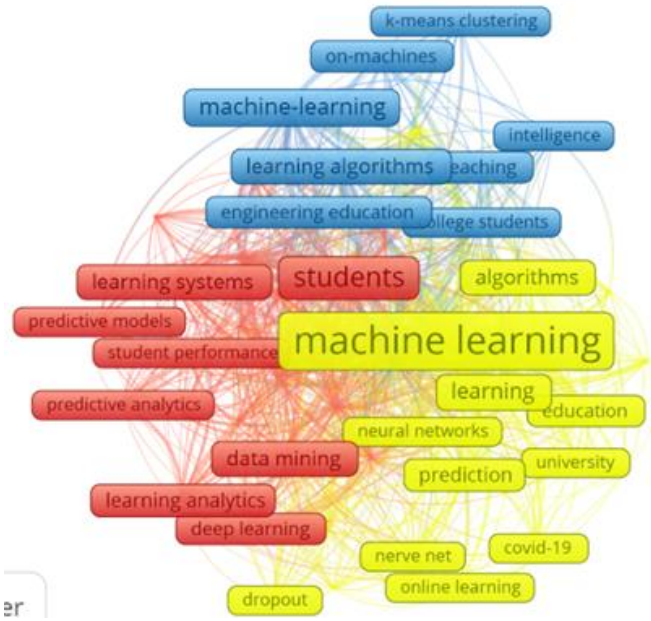

Figure 3. Co-occurrence analysis of the main keywords

ANALYSIS OF RESULTS

As can be surmised from **Figure 2**, the initial search yielded a total of 1792 articles. Given that all the articles come from the same database, it is perhaps unsurprising that no duplicates were found. After the reading of the titles and abstracts, 235 articles were selected for a full-text analysis. After an extensive review of the full texts, a final sample of 171 articles met the inclusion criteria and were included.

Keyword analysis of the selected studies

VOSviewer was utilized to create a co-occurrence analysis of the main keywords. In the grand total of 1216 keywords detected, only 52 meet the minimum threshold of 7. In **Figure 3**, the node area and font size are proportional to the number of occurrences of a certain keyword, thus larger nodes reflect the keywords that were mentioned more often. The line between nodes indicates when a keyword appears with another keyword.

Table 1. Cluster Analysis

Cluster	Topic	Keywords
Red	ML Models	Forecasting, Data Mining, Machine Learning Models, Predictive Analytics, Predictive Models, etc…
Yellow	Education	University, E-learning, Education, Intelligence, COVID-19, Online Learning, Machine Learning, Learning, etc…
Blue	ML Applications	Classification, Feature Selection, Dropout, Deep Learning, Prediction, etc…

Table 2. Descriptive statistics and individual reliability for all items

Journals	n	Impact Score 2021	*h*-Index	Quartile
IEEE Access	14	4.34	158	Q1
International Journal of Emerging Technologies in Learning	7	2.75	30	Q1/Q2
Security and Communication Networks	7	2.53	50	Q2
Mobile Information Systems	5	2.27	37	Q3
Wireless Communications and Mobile Computing	5	2.47	69	Q2
International Journal of Innovative Technology and Exploring Engineering	5	-	-	-
International Journal of Advanced Computer Science and Applications	4	1.16	23	Q3
Mathematics	4	2.84	43	Q3
PLoS ONE	4	3.58	367	Q1

In addition, it was possible to identify 3 main clusters whose topics and keywords are listed in **Table 1**. The nodes with highest number of occurrences and total link strength were "Machine Learning", "Students" and "Education Computing".

Demographic synthesis of the selected studies

Focusing on the topic of authorship, out of 616 authors, none wrote more than 2 articles. Using VOSViewer to conduct a co-authorship analysis, it was possible to conclude that no one co-authored more than 2 articles with other researchers. Thus, no significant clusters of authors were found.

In **Figure 4**, a graph displaying the number of publications per year for the years 2019 to 2022 can be seen. It is possible to conclude that the number of yearly publications on this subject that could be found in the SCOPUS Database has grown since 2019 with 2022 being the most productive year. Therefore, this trend indicates that interest in researching ML applications in the context of the higher education system has grown especially since the beginning of the COVID-19 pandemic.

The findings show that a total of 75 different journals were used to publish the 171 selected articles from the SCOPUS database. To present our results in a more concise manner, only the journals with at least 4 articles were included on **Table 2**. Using data from Resurchify, the impact score, *h*-index and quartiles for each journal were included on the table.

Thus, IEEE Access emerges as the most active journal in this field of study with 8,19% of the articles that made up the final sample. This journal is followed by the International Journal of Emerging Technologies in Learning with 7 publications and an Impact Score (2021) of 2,75 and the Security and Communication Networks with 7 articles and an Impact Score (2021) of 2,53.

In terms of the Impact Score (2021), 2 of these journals had an impact score above 3 with IEEE Access having the highest value of 4,34 average citations per document over the previous two years. Regarding the *h*-index, PLoS ONE (367) and IEEE Access (158) registered the highest values. In terms of publication quartiles, three of these journals fall within Q1 (top 25% of its subject category) and none fall within Q4 (lowest 25%). Overall, the open access nature, the frequency of publication and high number of citations have made IEEE Access the most impactful publication in this hot research field.

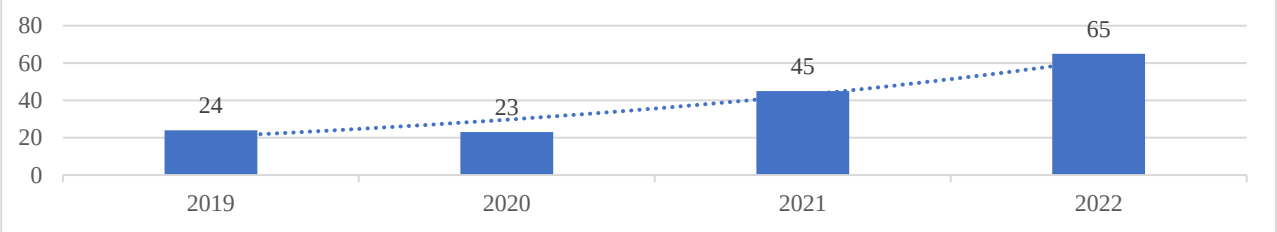

Figure 4. Number of publications per year

Figure 5 displays the geographic distribution of the growth of the research on ML in Higher Education since 2019. It is worth noting that an article can be produced by authors for more than one country. Regarding the geographical distribution of the publications, the People´s Republic of China (PRC) emerges as the country as the leading country contributing to the growth of ML in Higher Education research with a total of 32 articles, followed by the United States (24 articles), Saudi Arabia (16 articles) and India (13 articles). Conversely, it is also worth mentioning that the sanctions following the 2022 Russian invasion of Ukraine can explain, at least in part, the low number of Russian publications (1 article).

Analysis of the ML algorithms and main research themes

Regarding the research methodologies, most studies used quantitative methodologies. In **Figure 6**, the main applications of Machine Learning and Deep Learning were summarized in a taxonomy of different categories of ML algorithms and Deep Learning. The number of studies applying a particular algorithm is denoted with a bracket. The most widely used DL approaches were Neural Networks (34 studies), Artificial Neural Network (28) and Multi-layer Perceptron Neural Network (12). Supervised ML applications were the most applied by researchers, namely, Random Forest (64), SVM (61), Naïve Bayes (34) as well as regression techniques. These Supervised ML algorithms are popular due to their generality and the fact they are easier to interpret (Regression and Classification).

To analyze the main research themes, the papers were classified between five categories: Prediction of student performance and employability (71 studies); Improving student retention (38); Education quality, experience and satisfaction (32); Grading students (16) and Testing students (9). While papers can be included in more than just one category, the main findings can be summarized in the following section.

Prediction of student performance and employability: The most extensively researched application of ML in higher education relates to the possibility of predicting student performance. For instance, studies like (Rista and Mukli, 2022) employed a ML approach to predict, analyze and evaluate the potential causes of student absenteeism.

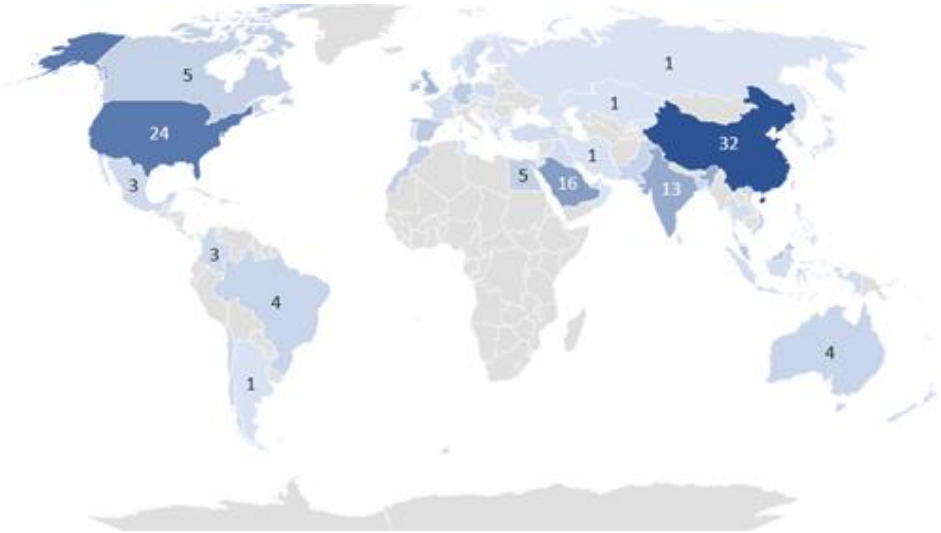

Figure 5. Geographical distribution of the publications

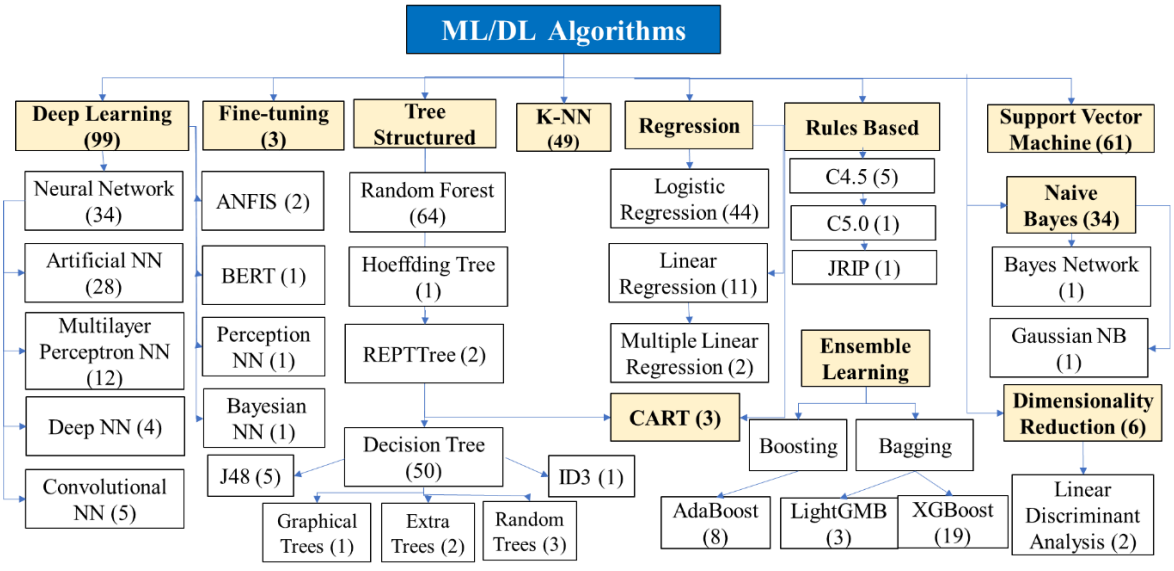

Figure 6. Taxonomy of ML Approaches based on (Shafiq et al., 2022, p. 10)

Additionally, several studies used data driven approaches to predict academic results such as exam scores, academic retention, degree completion and GPA (Tanuar et al. 2019; Musso et al. 2020). For instance, (Musso et al., 2020) using multilayer perceptron artificial neural network models with a backpropagation algorithm, classified levels of grade point average, academic retention, and degree completion outcomes in a sample of 655 college students. The study found that learning strategies were the best predictors of GPA and coping strategies were the best predictors for degree completion.

In addition, several researchers have employed ML based approaches to predicting the employability of college graduates in order to develop study plans to guide that match the demands of the labor market (Brockmann et al., 2019; ElSharkawy et al., 2022; Januzaj et al., 2022; Mewburn et al., 2020; Saidani et al., 2022; Sobnath et al., 2020). These kinds of studies are useful for HEI´s to develop a study curriculum that satisfies the demands of the job market.

(Saidani et al., 2022) focused on students who had the experience of doing an internship during their university course. The goal of this study was to develop an effective model to predict if a graduate will land a job after their internship using three gradient boosting classifiers: eXtreme Gradient Boosting (XGBoost), Category Boosting (CatBoost) and Light Gradient Boosted Machine (LGBM). In contrast to other studies like , the study found that these gradient boosting algorithms were the most effective in predicting employability. Additionally, the findings showed that the internship context influences the job prospects of graduates even more than the student context. Doing a face to face rather than online internship, obtaining a high grade in the internship and obtaining a certificate after doing the internship were found to be the most important factors that will determine if a student lands a job after their internship.

(ElSharkawy et al., 2022) focused on the prediction of employability of IT graduates, a sector with growing labor demand but faced with the mismatch between needs of academia and the labor market. The author sought to build a ML model using five distinct algorithms: Decision tree (DT), Gaussian Naïve Bayes (Gaussian NB), Logistic Regression (LR), Random Forest (RF), and Support Vector Machine (SVM). The model achieved higher accuracy that earlier studies with 100% accuracy in predicting IT graduates' employability using the Decision tree algorithm followed by logistic regression and SVM with 92%.

One of the few studies that focused on the experiences of students with disabilities was (Sobnath et al., 2020). The main goal of this study was to build a pilot predictive model that can be used to improve the job prospects of disabled graduates 6 months after graduation. Using a data driven approach, the authors concluded that age, college institution , level of qualification and type of disability were the most relevant factors in predicting the employability of students with disability. Regarding the disability variable, specific learning difficulty such as dyslexia, dyspraxia, or ADHD were shown to be a crucial variable of the model. From the four ML algorithms employed (Logistic Regression, Linear Discriminant Analysis, Logistic Regression and Decision Tree), Gaussian NB was the least effective at predicting the activity and industry in which students with disabilities will be employed six months after graduation. On the other hand, Decision Tree Classifiers and Logistical Regression models proved to be the most accurate being capable of predicting the occupation classification of disabled school leavers.

Finally, (Brockmann et al., 2019) was the only study that focused on students from underrepresented groups: first generation students from non-academic families, minorities, single parents and women. The study in question explored how computer science graduates from underrepresented groups can add value to software corporations. Using data from a job database, a ML system was deployed with three competing algorithms: Naive Bayes Classifier (NBC); K-Nearest Neighbors (KNN) and Support Vector Machine (SVM). Support Vector Machine was the best of all three algorithms. Aside from hard skills in programming, IT companies value job applicants with soft skills (creativity, conflict management, team building and organization skills) and foreign language abilities. In this aspect, graduates from underrepresented groups were found to be able to contribute with unique soft skills.

Improving student retention: ML algorithms are being implemented to reduce the likelihood of academic failure and develop solid strategies to mitigate the risk of students dropping out. Overall, most studies reviewed have found academic factors ("grades", "GPA", etc…) to be the most statistically significant in predicting student dropout. However, most studies have found social and demographic variables ("gender", "age", etc…) to be less statistically significant.

(Eegdeman et al., 2022) sought to compare the ability of ML algorithms to that of teachers to identify at-risk students in two distinct moments: at the beginning of the program and after the 10 weeks of the program. At the beginning of the program, the teachers were able to identify at-risk students more accurately than the ML algorithm. However, after the first 10 weeks of the program, the ML algorithm managed to outperform the teachers.

Several studies have also sought to explore how ML algorithms can be used in blended learning programs and in Massive Open Online Courses (MOOCs) that suffer from high dropout and failure rates (Borrella et al., 2019; Chi et al., 2023; Jha et al., 2019; Mourdi et al., 2020).

Education quality, experience and satisfaction: Improving the level of satisfaction of students namely in the context of online education after the COVID-19 pandemic has been one of the main applications of these technologies (Abdelkader et al., 2022; Ho et al., 2021). To this end, (Abdelkader et al., 2022) posited that feature selection (FS) increased the predictive accuracy of their ML model allowing them to predict student satisfaction with online education with nearly perfect accuracy.

(Ho et al., 2021) investigated the most important predictors in determining the satisfaction of undergraduate students during the COVID-19 pandemic using data from Moodle and Microsoft Teams. The results showed that random forest recursive feature elimination improved the predictive accuracy of all the ML models. The elastic net regression proved to be the most accurate model boasting a

65,2% explained variance. Regarding the level of satisfaction of students with distance learning, the overall level of satisfaction could be considered neutral with even most the most tech-savvy students preferring face-to-face education. Thus, the study found that most statistically significant factors in predicting student satisfaction with distance education were the preference for face-to-face education, the perceived effort made by teachers, the perceived appropriateness of adjusted assessment methods and the perception of online learning being well delivered.

Grading students: ML based approaches have also been deployed in grading students to automate the tasks of assessment giving students instant and bias-free feedback on their assignments. With the growth of MOOC´s, extensive research has been conducted to develop automatic assessment systems that can grade not just objective-type questions (i.e. multiple choices), but also more subjective questions like English essays (Han and Huwan, 2022; Wang, 2022).

(Wagstaff et al., 2019) presented a seamless, efficient, and accessible mobile solution to automate grading across multiple formats called Snaptron. Using TensorFlow and Keras and Deep Learning algorithms like CNN, the authors built an educational tool that could be used instead of traditional methods to grade tests. Just by taking a photo of a test, the application can recognize names and ID´s, handwriting patterns and grade the answers.

Testing Students: ML algorithms are being used to assess students and provide constant feedback to teachers both in a classroom and blended learning setting. Several studies have explored ML based approaches to combat cheating and ensure the academic integrity of student assessments (Kamalov et al., 2021; Sangalli et al., 2020). In online education, it is particularly changeling for professors to supervise students during exams increasing the risk of academic misconduct. (Kamalov et al., 2021) proposed a new ML based approach to detecting potential cases of cheating on online exams by applying Recurrent NN (RNN) together with anomaly detection systems. The proposed method yielded promising results on in various experiments significantly outperforming benchmark methods.

Other studies focused on the application of natural language processing models as educational tools and the potential risks they pose for the integrity of academic assessment. For example, (Gilson et al., 2023) showed that ChatGPT is capable of obtaining passing score for a third-year medical student in US Medical Licensing Examination. (Drori et al., 2022) explored the ability of ChatGPT-3 to solve university-level mathematics course questions at a human level, explain these questions at scale and generate new questions at a human level. The results showed OpenAI´s Codex transformer could solve university-level problems at 81% automatic accuracy.

MAIN CONCLUSIONS

In conclusion, this SLR sought to review the literature indexed on the SCOPUS databased over the previous 5 years (2019-2023) related to the application of ML solutions in HIE´s. Overall, the results show that the literature on this topic while still scarce is growing at a rapid pace and being mostly funded by public grants and universities. The PRC is the country that produced with the highest number of articles in the final sample, followed by the United States, Saudi Arabia and India. It was possible to conclude that ML techniques have been applied with positive effects in higher education particularly in predicting student performance, enhancing the quality of education and reducing student attrition. A wide variety of techniques were used, and most studies even used multiple algorithms to make comparisons to find the best model suitable for the dataset. The most widely used algorithms were Random Forest (64), SVM (61), Naïve Bayes (34) and Neural Networks (34) due to their generality and the fact they are easier to interpret (Regression and Classification).

Regarding the limitations of this review, only open access studies from the SCOPUS database were considered. Since the search was carried out in March of 2023 and only included articles in the final stage of publication, it was not possible to take into consideration all the publications for the year of 2023. In addition, the review protocol was not registered due to time constraints. Further research is required to close existing research gaps in this rapidly evolving field. Therefore, future research should seek to study and propose concrete applications of ML and other AI technologies in the context of universities and other HIE´s, especially related to their implementation in the context of developing countries and/or underrepresented groups. In addition, researchers should seek to build upon this study to explore how innovative generative AI solutions like ChatGPT could be used ethically within an academic context.

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