A Systematic Analysis of Machine Learning Studies in Education

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ABSTRACT

Machine learning has been transforming education and changing learning, teaching, and administration processes. However, studies analyzing the existing body of work and emerging research foci are lacking. To fill in the re-search gap, this paper presents a bibliometric analysis of articles on machine learning in education that were indexed by Web of Science Core Citation In-dices from 1979 to 2023. The study investigates publication patterns (articles per year and journals) and key research areas. A keyword co-occurrence analysis was conducted to identify the clusters of keywords which often co-exist in articles. The analysis revealed six clusters which correspond to the main research themes: profiling and prediction, assessment, intelligent tutoring systems, MOOCs, natural language processing, and prediction in distance learning. It is discussed that the newly emerging and rapidly developing research area focuses merely on applications of the technology, while ethical, pedagogical, socio-cultural, and administrative is-sues regarding machine learning in education need further attention.

CCS CONCEPTS

• **Computing methodologies**; • **Machine learning**; • **Applied computing**; • **Education**;

KEYWORDS

Machine Learning, Education, Bibliometric Analysis, Keyword Co-occurrence Network

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1 INTRODUCTION

Artificial intelligence (AI) is defined as the ability of computing systems to engage in human-like activities like learning, adapting, self-correction, and complex information processing [1]. The emergence of AI dates back to the 1950s and the works of John McCarthy during the period was acknowledged to be the first studies on AI [2]. The investigations on AI have continued since then with varying pace. The field witnessed some dormant periods due to reduced funding and interest; however, in the last decade, there has been exponential growth in this track. Rahioui et al. [3] (2023) defined two main approaches to AI: connectionist approaches, where cognitive function is obtained by building formal, mathematical neurons connected to one another in more or less complicated networks (neural networks), and symbolist approaches, where knowledge and reasoning are represented by a mathematical formulation or logic (using symbols). In recent years, learning cognitive functions from data has become the more preferred solution due both to the challenges of symbolist techniques in formalizing robust reasoning in a world with numerous exceptions and the potential afforded by accumulated data (big data). Therefore, the developments in machine learning (ML) have been the main driver of the growth of AI recently.

Machine learning, a sub-field of AI, refers to the techniques that enable computers to learn from data. It is also utilized to detect patterns in existing data and make predictions based on such patterns [4]. Supervised, unsupervised and reinforcement learning are three main types of machine learning. In supervised learning, learning materials fed into the system are labelled. The method is usually applied for classification and regression. The unsupervised one, which is applied in clustering tasks, involves unlabeled learning materials. Reinforcement learning applies a "learning-by-doing" approach where the parameters are updated for maximizing the reward and minimizing the penalty. It is mainly used for implementing autonomous agents [5].

Like many other fields, education sector has increasingly been using machine learning applications. However, comprehensive analyses and reviews of educational machine learning studies are lacking probably due to the rapid pace of development in this field. With a view to alleviate the problem, this paper presents a bibliometric analysis of the machine learning studies in education. Bibliometrics is a field that uses mathematical and statistical techniques to study publishing patterns in the distribution of information [6] and to map current knowledge and its evolution in a research domain [7]. It can describe a research field in relation to a variety of units such as keywords, authors, institutions, publication sources and citations besides providing insights into patterns and trends of research via network modelling and visualization [8]. Keyword co-occurrence analysis is of particular interest in this paper, since clusters of keywords which are often utilized together in articles indicate research themes in a field [9].

Within this framework, the present study investigates publication patterns and main research themes in educational machine learning research from 1979 to 2023 on the basis of bibliometric data and a keyword co-occurrence analysis of published articles. The research questions of the study are presented below:

- What are the journals and publication distribution by years of the articles on machine learning in education?

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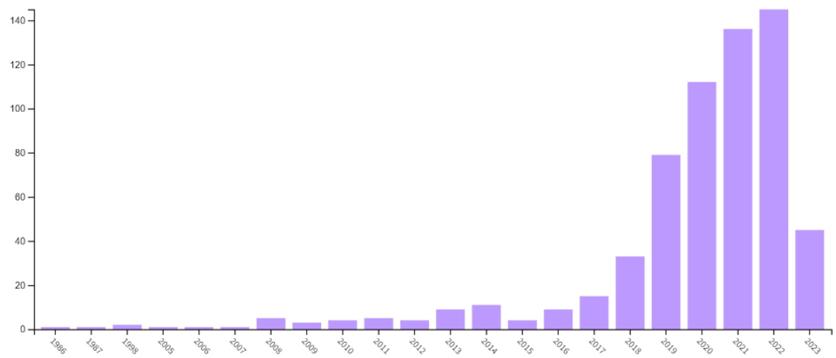

Figure 1: The distribution of articles (n=628) by year

- What are the clusters of co-occurred keywords in educational machine learning research and how can the evolution of research themes be understood according to them?

The paper is organized as follows: the study's methodology is described in the second section. The third section presents the results of the analyses regarding publication data, keyword clusters, and themes. The final section includes a discussion of the findings and conclusions.

2 METHODOLOGY

The bibliometric data analyzed in this study was retrieved from the ISI Web of Science, because the journals listed in citation indices constitute the most rigorous and prestigious ones. The relevant journal publications were located using the search term (SU=education & educational research) AND TS="machine learning". The search was limited to articles that were indexed by Science Citation Index Expanded, Social Sciences Citation Index, and Arts & Humanities Citation Index. The books, conference proceedings citation indices, and the Emerging Sources Citation Index were excluded. The years 1979 through 2023 were included in the search and as a result, 628 papers were accessed.

Vosviewer©bibliometric analysis software was utilized for the analyses. It is a free tool for displaying and exploring maps produced from network data. The bibliometric information was exported to Vosviewer©in tab-delimited format, including the whole record and the cited references. In order to merge similar but differently spelled keywords (such as ıntelligent tutoring systems/intelligent tutoring systems) and to get rid of typos, the keyword list was refined using a thesaurus file. As a result, 1817 keywords were obtained. The bibliographic information remaining after the screening process was fed into the analysis.

3 RESULTS

3.1 Analysis of Publication Data

3.1.1 Articles per Year. The distribution of articles on machine learning in education by years is presented in Figure 1. The figure reveals a dramatic growth in the number of publications after 2017. The figure also shows that such studies were scarce before 2008.

3.1.2 Journals. The articles included in the analysis were published in 132 different journals. The greatest number of articles were published in *Education and Information Technologies* (n=74), followed by *IEEE Transactions on Learning Technologies* (n=36) and *Interactive Learning Environments* (n=33). The ranking of the top 10 journals according to the number of articles published on machine learning in education is presented in Table 1.

3.2 Keyword Co-occurrence Analysis and Research Themes

The main points of publications are indicated by keywords, which also show the breadth of subject areas that can be studied within a given field of knowledge [9]. The results of the keyword co-occurrence analysis are displayed in Vosviewer©as a distance-based network visualization, where the distance stands for the strength of the relationship between two keywords, or the quantity of co-occurrences. A greater distance denotes a weaker connection between the two items. The item label size is proportional to the frequency (the number of occurrences) of the keyword in the publications, and different colors represent different knowledge domains clustered by the software's algorithm.

The keyword co-occurrence analysis reveals the most important keywords and keyword clusters which correspond to the main research themes in the field. The keywords which were used at least in 5 papers were included in the keyword co-occurrence network. The final network with 47 keywords, 6 clusters, 230 links and a total link strength of 580 is shown in Figure 2. As seen in figure, the most widely used keyword is "machine learning" (284 occurrences). It is followed by "educational data mining" (52 occurrences). "Artificial intelligence" and "learning analytics" keywords had 48 occurrences each and "natural language processing" was utilized in 26 papers. Other important keywords are "deep learning" (22 occurrences), "MOOCs" (21 occurrences) and "assessment" (16 occurrences).

In the next step, the keywords in each cluster and related work were carefully evaluated in order to determine the research foci of

Table 1: Ranking of the top 10 journals according to the number of articles

Rank	Journal	n
1	Education and Information Technologies	74
2	IEEE Transactions on Learning Technologies	36
3	Interactive Learning Environments	33
4	Computer Applications in Engineering Education	31
	Computers & Education	31
5	British Journal of Educational Technology	21
6	Educational Technology Society	19
	Journal of Science Education and Technology	19
7	International Journal of Electrical Engineering Education	16
	Journal of Computer Assisted Learning	16
8	Academic Medicine	13
	Educational Measurement Issues and Practice	13
	IEEE Transactions on Education	13
9	International Journal of Educational Technology in Higher Education	11
	Journal of Chemical Education	11
	Journal of Educational Computing Research	11
10	ACM Transactions on Computing Education	8

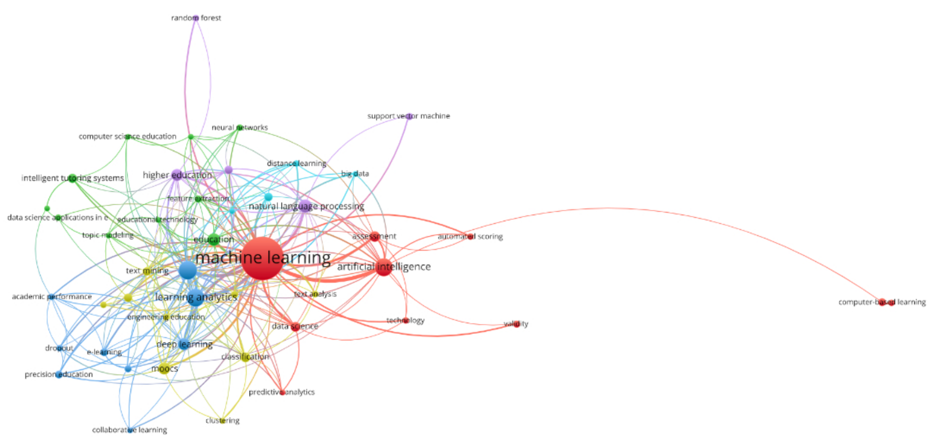

Figure 2: The keyword co-occurrence network related to educational machine learning studies from 1979 to 2023

the clusters and labels were assigned accordingly. Consequently, six keyword clusters were identified: profiling and prediction, assessment, intelligent tutoring systems, MOOCs, natural language processing, and prediction in distance learning. These are presented and discussed below.

3.2.1 Profiling and Prediction. Development of learner models or profiles that allow prediction is the most prevalent application of machine learning in education. Such models are used to predict dropout rate, academic performance, and admission decisions. Research focusing on dropout rate aims to detect at-risk students and improve retention. Demeter et al. [10] developed a ML algorithm to predict if and when first-time-in-college students will graduate. The results indicated that credit hours earned, college and high school grade point averages, estimated family (financial) contribution, and enrollment and grades in required gateway courses within a student's major were all strong predictors of graduation status. Academic performance was predicted according to student behavior [11–13] and earlier sample work [14]. Other cognitive and non-cognitive variables were also studied in relation to academic success. For instance, Musso et al. [15] applied an artificial neural network approach to predict students' grade point averages in a sample of 655 students from a private university. The study concluded that learning strategies was the best predictor of grade point average. Admission decisions constitute another category of machine learning based predictions in education. Andris et al. [16] used the support vector machine technique to predict college admission decisions of students according to spatial characteristics of campuses and students' home towns. The findings showed some spatial patterns that might favor students from certain geographic regions.

"Precision education" is a rising keyword under this theme. The term refers to personalized education in a deeper sense so that learners' individual differences and unique needs are of utmost importance. Luan and Tsai [17] discuss that although the terms "personalized learning", "individualized learning", and "precision education" have been used interchangeably, the phrase "precision education" is a relatively recent invention. Since its first use by Hart in 2016 [18], an increasing number of studies related to this concept have adopted machine learning approaches.

3.2.2 Assessment. Developments in ML and the availability of big student data enabled automated and adaptive assessment techniques in education. Instead of conventional exam settings, assessment can be integrated with learning processes for continuous monitoring of student performance. In recent years, automatic scoring and feedback functionality have proliferated especially in online learning. Such tools range from multiple-choice tests [19] to essay grading [20]. Using data mining techniques in student evaluations to assess instructor performance is another track of research under this theme [21, 22]. Such efforts have the potential even to change exam scoring of large scale national systems. For example, Cinar et al. [23] developed an automated grading system for open ended physics questions in Turkish at a university level course using machine learning techniques. The study indicated that open-ended questions could be used in Turkish national selection and placement exams which were traditionally based on multi-choice questions.

3.2.3 Intelligent Tutoring Systems. Intelligent tutoring systems which offer learners immediate, personalized instruction or feedback have been in existence for decades; however, recent developments in ML attracted more attention to such systems. The "intelligence" in these systems stands for the way they adapt themselves to the characteristics of the students, such as speed of learning, strengths and weaknesses of the learner, and preferred learning style [24]. Intelligent tutoring systems can be used for teaching content [25, 26] as well as diagnosing strengths and weaknesses of students and providing automated response [27, 28]. As the technology matures, the on-screen intelligent tutoring systems could be replaced by "Intelligent Tutoring Robots". Hu et al. [29] propose such a system based on robotic process automation technology which enables robots to observe people at work, analyze user processes repeatedly, and adjust automated processes accordingly. Hu et al.'s intelligent tutoring robot provided early warning to distance learning students. The study indicated higher academic performance of the experimental group, although no statistically significant result was found.

3.2.4 MOOCS (Massive Open Online Courses). A massive open online course (MOOC) is an online course designed for open access and unlimited participation on the Internet. MOOCs constitute an important theme within educational machine learning research due to several reasons. First of all, the popularity of MOOCs have continuously been increasing worldwide. Secondly, the massive and automated nature of such systems render them suitable candidates for ML applications. They usually offer large data repositories to researchers and require little if any human intervention in their processes. As the keyword co-occurrence map shows (Figure 2), MOOCs related research in educational machine learning often applied text mining, text analysis, classification and clustering. Furthermore, the lack of an emotional component in MOOCs triggered sentiment analysis-based studies in recent years. For example, Pan et al. [30] analyzed a large database of student comments from a MOOC using deep learning algorithms to classify students' academic emotions. The results showed that students' concerns mainly focused on two aspects: whether they could learn the subject, the other is the characteristics of teachers. "COVID-19" is another important keyword in this cluster due to the increasing interest in MOOCs during COVID-19 lockdowns.

3.2.5 Natural Language Processing. Natural Language Processing (NLP) is defined as a sub-field of machine learning which deals with a computer's capacity to comprehend, evaluate, alter, and synthesize human language [31]. This concept is another rising trend in ML research and constitute an important theme in educational machine learning research (Figure 2). The most popular applications of NLP are Chatbots that can comprehend user requests in everyday language and response automatically [32]. The keyword co-occurrence map in Figure 2 shows that the keyword NLP was often used together with the keywords: "supervised learning", "support vector machine", and "random forest". Because, supervised classification techniques like support vector machines and random forest are usually utilized for classification of natural language samples. As seen in Figure 2, the keyword "natural language processing" has strong links with the other keyword clusters. This indicates that it has been applied in many studies with different focus. It has been envisaged that NLP tools like ChatGPT can participate in active learning processes as a collaborative social entity and promote students' critical thinking and problem-solving skills [33].

3.2.6 Prediction in Distance Learning. Since distance education has been examined more in research than formal education, prediction in distance education was found to be a small but independent cluster. Prediction in distance education has been studied in relation to "big data" and "data models".

4 DISCUSSION AND CONCLUSION

This study provided insights into the publication patterns and research themes of articles on machine learning in education. The findings showed that, unlike many other research areas in education, this field of inquiry is rather new and the greater body of work was produced after 2017. It is also rapidly developing, the number of articles reached to 145 in 2022 from 15 in 2017. Although the articles published in 132 different journals, *Education and Information Technologies* is the most preferred one by the authors. This journal has published more than twice as many articles as its closest competitor.

The keyword co-occurrence analysis presented in this paper showed that the current educational machine learning research can be discussed under six titles: profiling and prediction, assessment, intelligent tutoring systems, MOOCs, natural language processing, and prediction in distance learning. This systematic clustering contributes to understanding and conceptualizing the machine learning studies in education. A close examination of the keywords and the contents of the related papers revealed that many studies focused on the application of machine learning techniques to a relatively limited scope of educational issues. Liu et al. [34] addressed two challenges of using ML techniques in education: 1) incorporating educational objectives into the formulation of technical ML problems, and 2) converting ML predictions into practical interventions. Therefore, our study suggests that the relevancy of ML to educational situations should be further addressed. It is anticipated that ML will continue to be influential in the future decades, so educational institutions should seek meaningful ways to utilize it for their purposes. Moreover, it was also observed that theoretical concepts have rarely been discussed in the analyzed articles. The atheoretical nature of the existing work can be attributed to the newness of the topic. As the research area matures, the educational community is expected to build stronger links with the theoretical backgrounds of the discipline while employing machine learning in their practices.

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