E-learning enhancement through educational data mining with Covid-19 outbreak period in backdrop: A review

Kudratdeep Aulakh [*], Rajendra Kumar Roul, Manisha Kaushal

Thapar Institute of Engineering and Technology, Patiala, Punjab, India

ARTICLE INFO

ABSTRACT

E-learning is fast becoming an integral part of the teaching- learning process, particularly after the outbreak of Covid-19 pandemic. Educational institutions across the globe are striving to enhance their e-learning instructional mechanism in accordance with the aspirations of present-day students who are widely using numerous technological tools — computers, tablets, mobiles, and Internet for educational purposes. In the wake of the evident incorporation of e-learning into the educational process, research related to the application of Educational Data Mining (EDM) techniques for enhancing e-learning systems has gained significance in recent times. The various data mining techniques applied by researchers to study hidden trends or patterns in educational data can provide valuable insights for educational institutions in terms of making the learning process adaptive to student needs. The insights can help the institutions achieve their ultimate goal of improving student academic performance in technology-assisted learning systems of the modern world. This review paper aims to comprehend EDM's role in enhancing e-learning environments with reference to commonly-used techniques, along with student performance prediction, the impact of Covid-19 pandemic on e-learning and priority e-learning focus areas in the future.

Practitioner Notes

What is already known about this topic:

- Educational Data Mining techniques are applied by researchers to extract valuable information from educational data.
- Application of EDM techniques can help educational institutions improve e-learning/online learning systems.
- The Covid-19 pandemic has forced educational institutions to switch to e-learning systems so that the learning process could continue without any interruption.
    What this paper adds:
- It provides an overview of selected past research papers related to EDM applications to e-learning, including the backdrop of the Covid pandemic period.
- It presents a review of past research pertaining to EDM use in e-learning from the perspective of student academic performance prediction.
- It highlights the growth of e-learning in recent years and the projections of increased significance of e-learning in the post-Covid era.
    Implications for practice and/or policy:

- Educational institutions around the world have to recognize the growing need to incorporate e-learning and other technology-assisted mechanisms for instructional purposes.
- Increased use of technology in education has necessitated academicians/administrators to restructure the teaching-learning process in tune with the changing times, with the help of new models proposed by EDM researchers.
- New, advanced EDM techniques proposed by researchers, can help educational institutions make the learning process more adaptive to the needs of the students and also support personalized learning.

1. Introduction

Educational Data Mining (EDM) is an evolving research domain that underlies the concept of 'Data Mining in Education' (Grigorova et al., 2017). It pivots around four key stakeholders — students, teachers, administrators, and researchers. EDM involves an extensive application of Data Mining techniques to large volumes of data obtained from educational institutions (Shahiri et al., 2015). According to a definition given by The International EDM Society, and also by (Baker et al., 2010), EDM is 'an emerging discipline' which is focused on 'developing

methods for exploring the unique types of data that come from educational settings,' together with the use of the developed methods 'to better understand students and the settings which they learn in.' The EDM technique is aimed at the extraction of hidden but useful information from huge educational datasets pertaining to educational settings at all levels — from the school level to the university level (Bhardwaj and Pal, 2012). EDM plays a very crucial role in 'mining' the most precise information about the behavior of students as well as gauging the efficacy of the learning process (Sana et al., 2019). The use of EDM methodology reveals useful knowledge about the educational settings, and facilitates the discovery of helpful trends and patterns from large and complex educational datasets (Han et al., 2011). (Fig. 1).

The application of EDM by researchers to e-learning environments is aimed at evaluating the teaching-learning process and suggesting improvements to the process from time to time. The common EDM application areas in e-learning include analyzing and visualizing educational data, examining student behavior, predicting student performance, learning-related suggestions for students, providing feedback to teachers, designing courseware, and scholastic planning, and laying out the study schedule (Romero and Ventura, 2010). Since the ultimate objective of educational institutions is to enhance existing education systems through better decision-making capability of the administrators (Silva and Fonseca, 2017). The four prominent spheres to which EDM research efforts, from the e-learning perspective are presently being directed include:

- Understanding the learning behaviors of students
- Evaluating or predicting student performance/grades
- Assessing student engagement and student satisfaction levels
- Analyzing the reasons behind student drop-out rates.

Researchers have been showing an increasing interest in the e-learning scenario, which is evident from the growth of published papers on e-learning, as shown in Fig. 2 which is based on the information drawn from ScienceDirect database. The reason why e-learning has been garnering the interest of EDM researchers is that the e-learning mechanism is being adopted by educational institutions over the past few years.

The figure depicts the growth in published works in e-learning area over the last two decades. The figure shows that published papers on e-learning systems in educational institutions witnessed a more or less continual growth from 1998 to 2015. Thereafter, from 2015 to 2018, there was a decline in published works, seemingly because of a greater focus of researchers on Artificial Intelligence and Blockchain. However, after 2018, research related to e-learning systems in educational institutions started recording notable growth again. More explicitly, the use of EDM techniques in e-learning systems has attracted renewed attention of researchers after Covid-19 pandemic, which brought about
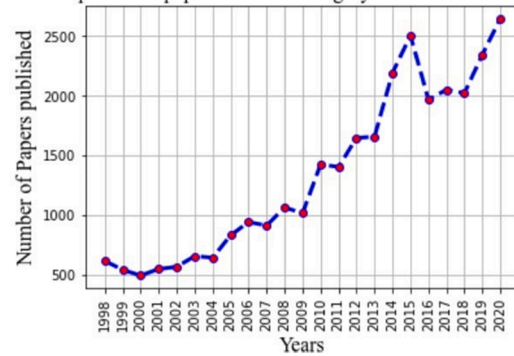
Fig. 2. Growth of published papers on E-Learning system in educational institutions.

a radical change in the educational sector across the globe.

This review paper focuses on the need to improve the e-learning method of education to align it appropriately with the ongoing era of rapid technological advancements, especially after the onslaught of the pandemic which brought the teaching-learning process to an unprecedented halt across the globe. Hence, the main objective of this review paper is to understand how EDM can be applied to e-learning systems with focus on the 'enhancement' perspective, including the need for improving the e-learning scenario against the backdrop of the pandemic (Azadi et al., 2021; Aqeel et al., 2022; Su et al., 2021; Abbas, 2020). The key research questions which comprised the backdrop of this objective were:

- Can EDM application to e-learning improve the design of e-learning systems to better suit student needs?
- How can student engagement and student performance be predicted in e-learning systems?
- Has Covid-19 pandemic affected the approach of educational institutions towards e-learning?
- What are the potential areas in e-learning on which educational institutions should focus in the post-Covid years?

This review is significant because e-learning systems having gained prominence in recent times, particularly after the pandemic crisis. Hence, the most important differentiating aspect of this review, in comparison to other surveys, is the backdrop of the pandemic, owing to which e-learning is projected to come to the forefront of education systems. The pandemic has forced educational institutions to scale up their online instructional mechanism so as to avoid interruptions to the learning process. With traditional classroom teaching having being

Fig. 1. Overview of the abstract.

brought to an unexpected standstill by the pandemic, institutions are switching over to online teaching methods at an impressive pace, both in the developed and the developing countries. Hence, this review draws attention to the increased scope for application of EDM techniques to improve e-learning systems for the future.

The review paper is divided into different sections which focus on EDM and e-learning, with the above-mentioned research questions in the backdrop. Section 2 of the paper gives an overview of EDM and e-learning, and also high- lights the diverse areas of application of EDM to e-learning environments. Section 3 comprises the Literature Survey, with focus on the use of EDM approaches for student performance pre- diction and the impact of the Covid-19 pan- demic on e-learning envi- ronment. Section 4 highlights the relevance of the review and its implications for e-learning systems. Section 5 comprises of discussion section. Section 6 highlights the open issues in EDM. Section 7 comprises the conclusion of the paper and future research directions.

2. Educational data mining and e-learning: overview

2.1. Educational data mining

2.1.1. The process of data mining in education

EDM is a research area which has originated from Data Mining (Anjewierden et al., 2007). It pivots around the educational setting, thereby marking a new application domain in Data Mining (DM) for extracting knowledge from educational data, as depicted in Fig. 3. Be- sides, knowledge extraction, EDM researchers are also concerned with recommending improvements to existing educational systems (Via- lardi-Sacín et al., 2009). EDM aims at augmenting student-learning models, which are typically indicative of the current knowledge of stu- dents as well as their learning attitudes (Baker et al., 2009).

EDM enables researchers to collect the data from diverse educational environments, analyze the data, under- stand the actions and behaviors of students, and determine their academic success (Whitley, 2018). Educational datasets are analyzed by EDM researchers with the help of various techniques from numerous fields. In fact, EDM involves the various disciplines of DM, including include Soft computing (Mitra and Acharya, 2005), Machine learning (Witten et al., 2017), Statistics (Hill et al., 2006), Probability (Karegar et al., 2008), Natural language (McCarthy and Boonthum-Denecke, 2011), and Artificial intelligence (Bhattacharyya and Hazarika, 2006). Besides these disciplines, re- searchers also use Database Systems and Recommender Systems (Bousbia and Belamri, 2014). They apply various tools, techniques, al- gorithms, and research designs to educational datasets and suggest learning-related improvements to educational institutions. The main orientation in EDM is towards the designing of methods, models, algo- rithms and tasks which can facilitate researchers in analyzing the data obtained from educational environments (Peña-Ayala, 2014). The analysis of educational data can be beneficial for students, educators as well as administrators because it can help them understand the learning process and work together to improve it (Baker, 2015).

2.1.2. Sources and types of data used in EDM

In e-learning systems, the educational data obtained by EDM re- searchers for analysis is the data available from different sources (Romero et al., 2010), some of which have been shown in Fig. 4.

In general, the diverse learning contexts which are generally considered important sources of data generation in e-learning are Computer-based education, Learning Management Systems, Intelligent Tutoring Systems, Interactive Education Settings, Adaptive Intelligent Hypermedia Systems, data-loaded learning activities like quiz, and educational games. Data obtained from different learning contexts, as mentioned in Fig. 5, can be evaluated by EDM researchers to offer so- lutions to questions pertaining to language, motivation, social discourse, etc (Koedinger et al., 2015). This data can facilitate analysts, researchers and academicians in improving e-learning environments so as to enhance the teaching- learning process (Khanna et al., 2016). The diverse aspects of e-learning process can contribute to the generation of various types and categories of data.

The use of EDM techniques can help researchers in downsizing huge educational data into valuable information (Baritchi, 2004). By analyzing educational data, researchers can obtain helpful pattern- s/trends from massive datasets (Bharati and Ramageri, 2010), discover unique patterns which are formerly unknown (Qureshi et al., 2013), and spot unidentified patterns in student behavior (Janczewski and Colarik, 2007). By using EDM techniques, researchers can offer potential solu- tions to a number of education-related issues associated with prediction of student enrollment in a learning program, syllabus arrangement, forecasting student success with course material, identifying learning patterns, and understanding student behavior (Kumar and Chadha, 2011).

2.1.3. Educational data mining techniques

EDM techniques are different methods which researchers use for mining knowledge from educational datasets. These techniques often overlap with other areas like machine learning, neural networks, data visualization, pattern recognition, and knowledge acquisition (Sumathi and Sivanandam, 2006). The application of different techniques to educational data enables researchers to help institutions identify prior- ity learning requirements of various student groups, recognize at-risk learners, an- alyze student and institutional performance, and opti- mize learning resources (Algarni, 2016). The use of EDM techniques has gained significance in recent years because the accountability of stu- dents' success largely lies with educational insti- tutions (Campbell et al., 2007). The application of EDM techniques can play a vital role in transforming the current teaching and learning models (Brown et al.,
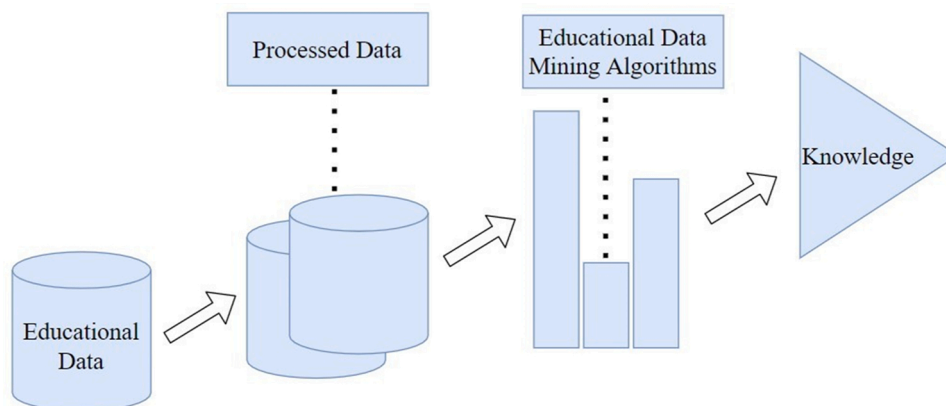

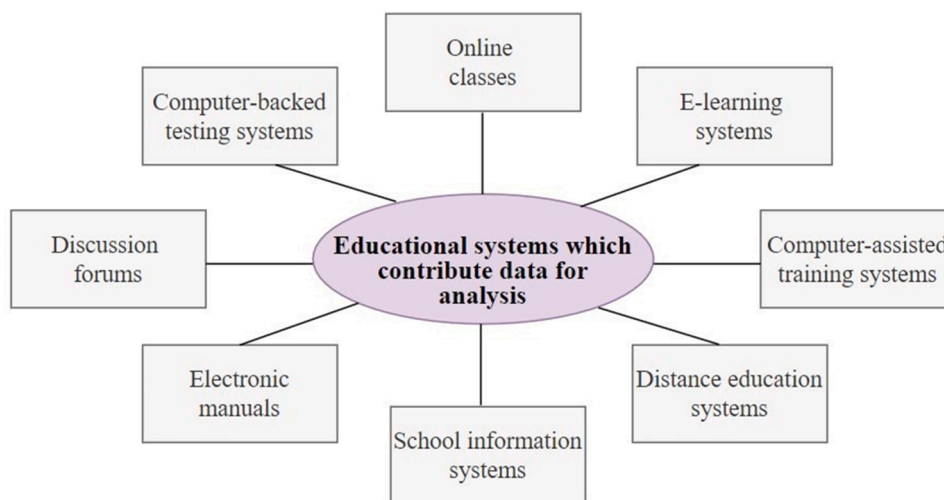**Fig. 3.** 'Extraction of Knowledge' component of EDM.

Fig. 4. Educational systems which contribute data for analysis.

Fig. 5. Types of data used for Educational Data Mining.

2015). The techniques facilitate the collection and analysis of educational data and assist the researchers in discovering previously undiscovered information, relationships and latest learning-related trends (ZoriÄ et al., 2020). By using EDM techniques, researchers can study the learning process exhaustively and provide useful suggestions with regard to improvement of student performance, course selection by students, student retention, and regulation of the finances of an educational institution (Goyal and Vohra, 2012).

There are a number of techniques which can be applied to educational data, depending on the pre-determined task of a particular data mining process. Commonly, there are four data mining tasks: Prediction, to forecast student performance (Şen et al., 2012); Classification, to categorize data into fixed groups (Nisbet et al., 2009); Clustering, to group together similar objects (Larose and Larose, 2014); and Association, to find interesting relationships amongst different data variables (Raval, 2012). In addition, the Regression technique is also widely used by EDM researchers. Table 1 briefly summarizes the common EDM techniques and their application scenarios.

EDM researchers can use one — or a combination — of techniques to analyze educational datasets, depending on the research objective. The choice of specific techniques is largely governed by the researchers' standpoint as regards a particular educational aspect (Hanna, 2004). The use of various techniques allows researchers to offer insights to

teachers and administrators for the purpose of tracking students' academic progress and evaluating the effectiveness of different instructional practices (Hamilton et al., 2009). EDM techniques can pave the way for optimization of institutional proficiency, and enhance learning outcomes by offering a personalized, interactive and adaptive learning environment for students (Papamitsiou and Economides, 2014). EDM techniques can be a powerful method for assessing whether the learning material keeps the students interestingly engaged with the study course (Cocea and Weibelzahl, 2009). The knowledge obtained by EDM researchers via the use of various techniques can be beneficial for assessing the academic progress of students, use of innovative teaching methods by teachers/instructors, and the education-centric decision-making process of academic planners (Jacob et al., 2015).

2.2. E-learning

The term 'e-learning,' first used in the year 1998, refers to a technology-assisted learning system which is commonly known as Web-based learning or Internet-based learning. It is a new-age learning environment in which different types of learning materials and digital technologies are used for providing a customized, learner-focused, and inter- active educational environment to students (Rodrigues et al., 2019). The e-learning environment is, therefore, a combination of two

Table 1
EDM application scenerios and techniques used.

Educational Data Mining Application Scenario	Technique Commonly Used
Prediction of student performance/grades; understanding student behavior	Prediction
	• Decision Tree Algorithm • Support Vector Machine • Neural Network
Categorization and profiling of students; finding out their learning styles/preferences	Classification
	• Decision trees • K-nearest neighbour • Statistical analysis • Bayesian classification • Rule-based methods • Neural Networks • Memory-based reasoning • Support vector machines
Grouping of students according to knowledge and content- interaction patterns; grouping of similar course materials	Clustering
	• K-means • K-medoids • Probabilistic clustering • Relocation algorithm • Agglomerative algorithm • Divisive algorithm • Density function Clustering • Density-based Connectivity
Study of relationships in student behavior patterns; identifying problems in teaching	Relationship Mining • Casual Data Mining • Association rule mining • Sequential Pattern Mining • Correlation Mining
Prediction of numeric values (continuous values) in a given dataset, for analysis of dependent-variable and independent-variable rela- tionship	Regression • Linear Regression • Logistic Regression • Polynomial Regression

key concepts (i) learning; and (ii) technology. E-learning is one of several technology-assisted learning systems — besides virtual learning, m-learning etc. — in which the utilization of computerized methods is conceptualized for the objective of facilitating the teaching-learning process (Aparicio et al., 2016). The e-learning methodology facilitates numerous types of interac- tions and conversations which can enable close association between teachers and students (Calvert, 2005). E-learning is aimed at offering a configurable educational network in which learning materials, learning instruments and instructional ser- vices are amalgamated into one distinct solution for creating and delivering educational or training content in a fast, effective and economical manner (Ong et al., 2004). In the e-learning system of ed- ucation, knowledge is available to all learners without any incongruity linked to time restrictions or geographical location (Sun et al., 2008). In fact, the biggest benefit of e-learning is that the technology-assisted learning models ensure that the constraints of time and space do not impact the student-to-student interactions and student-to-teacher communication (Katz, 2002). Based on its different definitions, the concept of e-learning can broadly be categorized into the following

groups (Sangrà et al., 2012):

- A learning system driven by technology
- A learning system involving communication and interactivity
- A learning system centered on delivery system
- A learning system oriented towards educational model.

E-learning has, over the years, become a rapidly-progressing trend in education (Wang, 2003). It is one of the most im- portant applications of digital technologies in learning environments (Rakic et al., 2020). E-learning is the process of teaching and learning online via network technologies, marking an extremely powerful response to the ever-increasing need for education (Zhang et al., 2004). E-learning systems offer a wide array of multimedia and interactive educational resources which can contribute to the designing of suitable educational environments for students in various situations (Haughey et al., 2008; Bates, 2008; Cleveland-Innes and Garrison, 2010).The e-learning mode of education delivery can yield almost the same learning outcomes — generally assessed in grades or marks – for students as the traditional classroom system (Russell, 2001). Overall, e-learning can make the educational processes quicker and more effective than traditional classroom-teaching methods.

2.2.1. Role of teachers in e-learning environments
The digital era has brought along rapid progress in the use of infor- mation and communications technologies, due to which there has been a momentous transformation in education systems around the globe (Arinto, 2016). The emergence of the e-learning concept has brought about a notable change in the role of teachers as compared to the traditional classroom-learning systems. The responsibility of teachers has evolved from that of being merely a dispenser of knowledge to that of being the curator of innovative spaces in which students can explore knowledge (Siemens, 2008). In contrast to the previous educational method of teacher-centric knowledge transmission, the new education systems focus on the student-centric knowledge generation method (Armellini and Jones, 2008; Swan, 2020). This is so because e-learning environments involve widespread availability of massive amounts of information which underline a vast range of student-teacher interactions that are continually generated in an educational setting (Abd Elaal, 2013). As such, there is greater emphasis on the role of teachers in terms of the design of learning environments conducive to the needs of stu- dents (Anderson, 2004; Bennett et al., 2009).

The present-generation students are able to actively benefit from e-learning environments because of their ca- pability to interact with different forms of technology for diverse purposes (Vai and Sosulski, 2011; Ko and Rossen, 2017; Sahoo et al., 2020). Therefore, owing to the expansive use of e-learning systems of late, teachers have to undertake a big responsibility in study-course development which needs to be reformulated in accordance with use of technology in education (Abrioux, 2001). Teachers have to adapt their teaching methods to modern-day e-learning environments in which the learning courses are quite prominently based on resource (Naidu, 2007) or online dialogue (Jara and Mohamad, 2007). Teachers are expected to play a more pro- active role in the e-learning environment, so that digital-education services can be improved and the reach of these services can be expanded to all students in the future (Falakmasir and Habibi, 2010).

The engagement of students with e-learning materials offered by educational institutions has become a crucial fac- tor for improving the chances of students' academic success. The advancements in technology have enabled teachers to manage online courses for learners by using online platforms such as Google Classroom, Udemy, etc. With digital channels making it possible for teachers to reach study materials to their students, the use of Learning Management Systems has become quite common. The use of online platforms and other technologies by teachers have given students the advantage of accessing the learning materials from any place, on any Internet-connected device, such as personal

computer, laptop, smartphone, etc. This online access to study materials online has emerged as a real savior for education systems during the Covid-19 pandemic.

2.2.2. Recent trends in E-learning

The emergence of diverse e-learning scenarios and the rapid expansion of e-learning content have marked the advent of new technology-based e-learning trends, as illustrated in Fig. 6. Some of these trends, such as mobile learning, are already being incorporated in the e-learning process. However, a few new trends, like the use of Augmented and Virtual Reality, are somewhat futuristic trends which are expected to gain ground in the coming years. In addition, new technologies like the Internet of Things (IoT) also mark a significant technological advancement in the field of e-learning (Soni, 2019). There is great focus on how IoT can be applied to e-learning (Priatna et al., 2020), and also on leveraging IoT for bringing about an improvement in learning outcomes for students (Kassab et al., 2020). Besides IoT, another technology set for wide application in e-learning is cloud computing which will apparently enhance the efficiency of e-learning process due to the cloud-storage advantage (Malhi et al., 2020). Artificial Intelligence is another modern-day technology which can contribute immensely to the transition to e-learning (El Gourari et al., 2020) and to a more personalized learning system for students, especially in the wake of the Covid pandemic.

The latest trends in e-learning are largely aimed at identification of the learning-content space, development of new e-learning content and personalization of learning content for new-generation learners.

2.3. Application of educational data mining to e-learning

Researchers can apply various EDM techniques to e-learning scenarios to analyze educational datasets from the perspective of enhancing the educational process in the digital age. From a practical view, researchers can use valuable information from student-learning data for assessing an educational setting, recommending qualitative improvements to the instructional systems, and laying the foundation for an enhanced learning process (Romero et al., 2004). The application of

EDM methodology to e-learning includes some specific tasks, such as evaluation of students' learning performance, personalizing student learning via course adjustments and learning suggestions, assessing online-learning content, and developing suitable models to understand learning behavior of students in e-learning courses (Castro et al., 2007).

From the functional perspective, some distinct areas of application of EDM to e-learning environments include identification of student complaints, analysis of student drop-out rates, and comprehensive assessment of student and teacher performance (Ali, 2013). Meanwhile, with reference to higher education, the main application areas of EDM are: student performance forecasting, evaluation of student learning, and facilitating teaching and research work (Ray and Saeed, 2018). Broadly speaking, there are four key EDM application areas in e-learning (Prabha and Shanavas, 2014), as illustrated in Fig. 7.

On the whole, there are wide-ranging applications of EDM in e-learning for improving the teaching-learning process in tune with the needs of the students.

3. Literature review

To compile the literature review of EDM application to e-learning, some relevant past research papers published between 2015 and 2020 were selected. However, a few papers from previous years and early 2021 have also been included because of their significance to the topic and its implications for e-learning. The words included in search query were: 'Application of educational data mining to e-learning'; 'Educational data mining techniques and e-learning'; 'Educational data mining and student performance prediction in e-learning;' and 'online learning during Covid-19 pandemic.'.

The literature survey has been divided into three sections, based on the grouping of relevant published papers. The first section includes papers related to use of EDM in e-learning in general; the second section includes papers related to EDM use for student performance prediction in e-learning systems; and the third section includes papers related to study of impact of Covid-19 pandemic on e-learning environment. The criterion for selection and grouping of the papers for first two sections

Mobile learning (m-learning)	Delivery of educational content on mobile devices
Adaptive learning	Personalization of educational content based on student' individual needs
Micro-learning	Delivery of educational content in short portions/chunks focused on specific topic
Artificial Intelligence	Guiding students through different phases of the learning process
Social learning	Using collaborative tools for human interactions during teaching-learning process
Video-based learning	Using video content for instructional purposes
Game-based learning	Using games to enable students to interact with learning materials
Immersive learning	Adopting technologies like Augmented Reality & Virtual Reality for instructional purposes
Learning Management Systems	For creating, administering and storing digital learning content

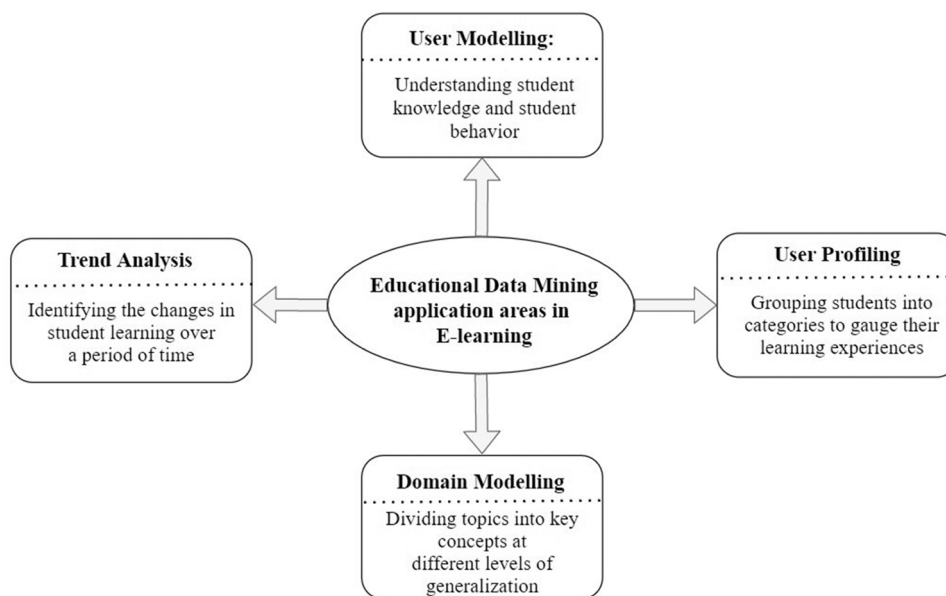**Fig. 6.** Recent E-learning trends.

Fig. 7. Key areas of Educational Data Mining application in E-learning.

was that the papers either involved the use of different EDM techniques to e-learning or presented some specific approaches to improve e-learning systems. The papers reviewed in the third.

section mainly pertain to an analysis of e-learning environment during Covid-19 pandemic.

3.1. Use of educational data mining methodology in e-learning environment

The scope of resolution of diverse education-centric problems through the use of EDM to educational data was surveyed by (Ganesh and Christy, 2015).

EDM techniques were applied by (Gushchina and Ochepovsky, 2020) to an e-learning system with the intention of understanding the behavior of students and their interest level with educational content.

An e-learning system to overcome the challenges related to e-learning platforms has been proposed by (Appalla et al., 2017), based on the common challenges hampering the effectiveness of e-learning systems and delivering personalized educational materials to students.

An assessment of student engagement in a technology-mediated education system was attempted by (Henrie et al., 2015) with the help of different student-engagement evaluation measures, like surveys and other quantitative self-report meth- ods, as well as observational measures.

A case study for enhancing e-learning systems was presented by (Jovanovic et al., 2012), who used data mining on educational datasets pertaining to student behavior and cognitive styles.

The effectiveness of web-based courses and e-learning systems for improving overall student-learning experi- ences was studied by (Ashraf and Khan, 2017) to highlight that e-learning systems can enhance the self-learning ability of students.

An understanding of e-learning from the standpoint of time conti- nuity as a distinct characteristic was attempted by (Wan and Niu, 2019), who spotlighted the acute scarcity of information faced by e-learning systems.

The application of EDM for evaluating the behavior of students using online learning platforms has been discussed by (Jie et al., 2017), who used EDM techniques and algorithms to analyze the study behavior of students based on data related to students' landing behavior and resources-explored behavior.

The core concepts of EDM, Big Data in Education, and online learning platform were studied by (Zhang and Qin, 2018), who elabo- rated how raw educational data can be transformed into knowledge with the help of EDM techniques.

The integration of mobile learning methodology into e-learning system was studied by (El-Sofany and El-Haggar, 2020) to focus on the effec- tiveness of mobile learning methods in e-learning environments for improving the learning outcomes of students.

Technology-assisted self-directed learning was discussed by (Alti- mari et al., 2012), with focus on learning objects and integration of repeat-use content units into personalized learning paths of students.

E-learning and student engagement levels in different higher-education online learning platforms were studied by (Grubišić et al., 2020) to track student learning activities and student knowledge.

In brief, the research papers reviewed in this section highlight the fact that although EDM is a fairly new research domain, the efforts of researchers to analyze educational data for improving e-learning sys- tems have been quite significant. The popularity of e-learning systems has increased manifold in a short time span because of the 'adaptively' advantage which has transformed the learning process for students. There has also been a vast expansion of student- information databases because of a remarkable growth in the availability of online education resources. Researchers can mine valuable knowledge from educational datasets and facilitate the decision-making process of educational institutions.

3.2. Application of educational data mining techniques to predict student performance

In e-learning related research, an attempt was made by (Daghestani et al., 2020) to gauge the impact of learning materials with student engagement, by drawing attention to the concept of Artificial Intelli- gence for providing new prospects to make e-learning more effective.

A new approach for the application of EDM to understand student performance in e-learning environments has been presented by (Injadat et al., 2020), who studied the use of multiple techniques for forecasting student performance to support their academic progress.

EDM has been described by (Rawat and Malhan, 2019) as a practice in which useful information is automatically obtained and seg- mented from the educational data sources, and algorithms are used for student-performance prediction.

A study of use of supervised data mining techniques to understand

students' learning environment interactions and their performance in exams was conducted by (Tomasevic et al., 2020).

Different approaches and applications of EDM were studied by (Kaur and Bathla, 2018) from the context of prediction of student performance after analyzing hidden trends and patterns in voluminous educational datasets.

Fast-paced developments in the EDM and Learning Analytics have been highlighted by (Kausar et al., 2018) who focused on integration of EDM techniques in a personalized e-learning system, and underlined the need to obtain valuable infor- mation in an adaptive manner from educational data.

The application of Recommender systems in e-learning was

Table 2

Summary of EDM techniques/approaches presented.

Name of the paper	Reference No.	Purpose	Technique/Approach	Outcome
Recommender system for predicting student performance	(Thai-Nghe et al., 2010)	To predict the performance of students in e-learning scenario	Application of Recommender systems in e-learning	Better student- performance prediction outcomes as compared to conventional regression techniques
Authoring tutored, adaptive e- courses in a personal learning environment: a dynamic syllabus and dynamic assembly approach	(Altimari et al., 2012)	To study how Learning Objects can be changed into content units for repeated usage for students	Proposed an adaptive, learner- centric Personal Learning Environment (PerLE)	Technology-assisted learning can be enhanced by dynamically integrating reusable content units into students' personalized learning paths
Using data mining on student behavior and cognitive style data for improving e- learning systems: a case study	(Jovanovic et al., 2012)	To analyze student behavior and cogni- tive styles	Clustering, Classification	Focus on preprocessing of data, selection of attributes, and optimization of parameters can improve student performance
An analysis of the determinants of students' performance in e-learning	(Castillo-Merino and Serradell-López, 2014)	To study the key factors affecting student performance in e-learning systems	Using data from an experimental system established as part of eLene-EE project	Motivation is the most significant variable affecting student performance and learning efficiency in e-learning set- up
Applications of educational data mining: a survey	(Ganesh and Christy, 2015)	To identify algorithms with high reliability for future EDM research	Evaluation of clustering and classification algorithms	Suggested potential directions for EDM in future
An efficient educational data mining approach to support e-learning	(Appalla et al., 2017)	To understand reasons for in- effectiveness of e-learning systems	Proposed e-learning systems using five knowledge-input steps	Proposed e-learning systems overcame challenges pertain- ing to e-learning platforms
Effectiveness of Data Mining Approaches to E- Learning System: A Survey	(Ashraf and Khan, 2017)	To study how data mining approaches that contribute to enhancement of e-learning environ-ment	Intelligent Adaptive system	Improvement in real-life e-learning environment
Application of educational data mining on analysis of students' online learning behavior	(Jie et al., 2017)	To evaluate behavior of students using online learning plat- forms	Study of log data generated in specif- ically designed Autonomous Learning Platform	Teaching content should be orga- nized according to students' study behavior for op- timizing teaching strategies
Student performance prediction using educational data mining tech- niques	(Kaur and Bathla, 2018)	To implement EDM techniques for predicting student performance and learning behaviors	Naïve Bayes and Support Vector Machine techniques	Extensive use of DM algorithms is crucial for the purpose of decision-making and student anal-ysis from diverse aspects
Integration of data mining clustering ap- proach in the personalized E-learning system	(Kausar et al., 2018)	To highlight fast- paced developments in EDM and Learning Analytics fields	Approach for integrating Clustering technique in personalized e-learning system	Identification of the best educational set- tings for students to enhance their learning capabilities
A brief analysis of the key technologies and applications of educational data mining on online learning platform	(Zhang and Qin, 2018)	To introduce core concepts of EDM, Big Data in Education, and online learning platform	Classification of important data mining technologies	Laid out directions for future research as Big Data can have a substantial impact on online education
An evaluation of student performance at e-learning platform	(Rakic et al., 2019)	To explore the assessment of student performance at e-learning platforms	K-means Clustering, Linear Regression, and Social Network Analysis	Students' success is hugely impacted by digital learning content at e-learning platforms
A hybrid e-learning recommendation approach based on learners' influence propagation	(Wan and Niu, 2019)	To focus on time continuity and acute scarcity of information faced by e-learning systems	Proposed Hybrid Filtering recommendation approach	Personalized and diversified recom- mendations can make e-learning systems more efficient and adaptable to student needs
Adapting gamified learning systems using educational data mining techniques	(Daghestani et al., 2020)	To gauge the impact of learning materials with student engagement	Proposed an Adaptive Gamified Learning System (AGLS)	Artificial Intelligence (AI) can make e-learning more effective by increasing student engagement and learning performance
The effectiveness of using mobile learning techniques to im- prove learning outcomes in higher edu- cation	(El-Sofany and El-Haggar, 2020)	To gauge the effectiveness of use of mobile learning methods in e-learning environments	Integration of mobile-learning methodology into e-learning system	Mobile-learning methods offer greater flexibility to students for accessing educational content
Data mining of students' behavior in E- learning system	(Gushchina and Ochepovsky, 2020)	To understand students' learning behavior	Cluster analysis method, V-fold cross-checking, data analysis and visualization	Gauged student interest levels, evalu- ated quality of learning materials
A common model for tracking student learning and knowledge acquisition in different e-Learning platforms	(Grubišić et al., 2020)	To track student learning activities and student knowledge	Proposed a model aimed at Tracking Student Learning and Knowledge (TSLAK)	Evaluated student engagement levels with e-learning courses used for higher education
Systematic ensemble model selection approach for educational data mining	(Injadat et al., 2020)	To understand student performance in e-learning environments	KNN, Random Forest, SVM, Naïve Bayes, LR and Multi- Layer Perception	More accurate prediction of student performance for supporting their academic progress
An overview and comparison of supervised data mining techniques for student exam performance prediction	(Tomasevic et al., 2020)	To study students' learning environment interactions and their performance in exams	Model-based approach, Similarity- based approach	Probabilistic approach Predicting students' exam performance and forecasting dropout risk and future achievements of students

considered by (Thai-Nghe et al., 2010) with focus on recommendation of books, papers, and other educational materials to students in an e-learning environment.

The need for assessment of student performance in e-learning platforms has been highlighted by (Rakic et al., 2019) who listed the benefits of e-learning platforms in terms of flexibility in teaching as well as wide availability of learning content.

The key factors that affect student performance in e-learning systems have been underlined by (Castillo-Merino and Serradell-López, 2014) who said that student performance depends on several variables, including the abilities of students, teaching methods and technologies used by educators, and technology adoption level of institutions.

To summarize, these two sections of literature survey show that researchers have focused on student-performance prediction by ascertaining interconnected features that affect performance. The survey underscores the need for defining, evaluating and comparing student academic performance in e-learning systems and conventional classroom-teaching methods. The review also shows that widespread use of e-learning systems has necessitated the application of more accurate mechanisms for dynamically predicting student performance.

On the basis of the literature survey of published papers included in Sections 3.1 and 3.2, a summary of EDM methods used, or approaches presented, by researchers is given in Table 2.

The table shows that the academic performance of students is usually predicted by researchers with the help of EDM techniques like Classification (Naive Bayes, K-Nearest Neighbor, Random Forest); Clustering (K-means); Prediction (Support Vector Machine, Decision tree); Regression and Relationship Mining. These techniques are widely applied by researchers to analyze e-learning environments (Silva et al., 2021); understand learning behavior (Aguinis et al., 2021), academic per- formance (Wiliam and Thompson, 2008) and learning styles of students (Dwivedi et al., 2019) and provide feedback to the e-learning stakeholders (Shvets et al., 2020).

3.3. | Review of e-learning environment during Covid-19 pandemic

A global perception of e-learning scenario during lockdowns due to Covid-19 pandemic has been presented by (Radha et al., 2020) with emphasis on improved self-learning skills of students especially those familiar with web technology.

Online education has been described by (Dhawan, 2020) as a panacea for learning during Covid-19 pandemic period because the pandemic has resulted in a scenerio in which providing online education to students is no longer an option for educational institutions; it has become a necessity.

An affirmation that Internet played a key role to support the teaching-learning processes during the pandemic crisis has made by (Favale et al., 2020) who stressed the availability of Internet connectivity was crucial for supporting the teaching- learning processes during the pandemic.

The level of student satisfaction in e-learning systems during the pandemic has been studied by (Saxena et al., 2021) who exam- ined the impact of the crisis on the quality of e-learning processes based on factors like Internet content, responsiveness, assurance, and reliability.

The need to develop effective e-learning systems against the backdrop of Covid-19 pandemic has been underlined by (Ananga, 2020) who noted that the rapidly increasing use of Internet for education worldwide has put the spotlight on demand and supply of learning materials.

In some of the other papers pertaining to e-learning review during Covid-19 pandemic, (Yildiz et al., 2020) highlighted that the transition to online and distance education has, by and large, had a positive impact on students. Meanwhile,

Nikou and Maslov (2021) focused on perceived utility and convenience of e-learning systems; (Tawafak et al., 2021) emphasized on improved behavior intention of students for using e-learning technologies because of the pandemic impact; and (Garad et al., 2021)

underlined the crucial role played by e-learning infrastructure for making distance learning more effective during the pandemic. In addition, (Wang et al., 2021) highlighted sustainable development goals in education due to the pandemic impact; (Zarei and Mohammadi, 2021) studied e-learning infrastructure from the perspective of developed and developing countries; (Qiao et al., 2021) analyzed how online learning programs are being developed/adopted by institutions as a result of Covid; and (Rajab et al., 2020) stressed on the need to make e-learning systems more effective by extending the reach of technology to students.

A tabular summary of the review of published papers related to study of e-learning systems during the Covid pandemic is presented in Table 3.

With the onset of the COVID-19 pandemic, healthcare systems around the world have been under immense strain. This pandemic has had an impact on all aspects of life.

Some other papers included in the study investigates how contingencies disturb existing theoretical models and their consequences for online purchases in the post-COVID-19 age. During the COVID-19 crisis, customers prefer to use applications on websites for search and purchase (Al Halbusi et al., 2022; Moradi et al., 2021).

The paper rebuilds and constructs the revival, experts, professionals, and academia must evaluate changes in the fundamental principles, primary assumptions, and business organisations' situations related to the service industry and practise framework (Fu et al., 2021).

To accomplish sustainable education, social media plays an essential part in the learning behaviour of university students. The impact of social media on long-term schooling is becoming an important and motivating component (Abbas et al., 2019).

The usage of the internet and social media technology has arisen as an essential instrument of human civilization, and the evolution of technological integration, cyberspace, and web-technology has become standard practise in educational institutions. Online use among students has become crucial in learning behavior; yet, excessive internet and social media use leads to internet addiction (Khazaie et al., 2021).

The first step in understanding how the COVID-19 pandemic has used the funding resources already available and what kind of spending would be required to successfully prepare for the next pandemic is to identify how much has been spent in the health sector as a result of the pandemic. In order to comprehend the financial background of the pandemic and the relative scale of shift in expenditure that would be required to effectively avert the next global pandemic, it is important to look at global health spending at the beginning of the pandemic (Micah et al., 2023).

The emergence of the COVID-19 epidemic has sparked a global crisis that has forced the closure of educational institutions all over the planet. This study intends to investigate the factors that influence students' intentions to use e-library services during the tough COVID-19 pandemic (Rahmat et al., 2022).

On account of the review, it is evident that instructional dimensions are set for a notable change in future, after the pandemic. On one hand, it would be crucial for educational institutions to adopt new technologies and provide an excellent digital framework for education while, on the other hand, students will have to gain proficiency in the use of learning-technology tools — like computers, mobile devices, Internet etc. — and also learn to efficiently interact with these tools. However, it is important that universal and affordable access to the Internet should be available to students so that they can benefit from technology-assisted education environments.

4. Relevance of the review and implications for e-learning

4.1. Relevance of the review

This review paper is relevant in present times because it focuses on the need to improve the e-learning method of education to align it appropriately with the ongoing era of fast-paced technological developments. The relevance of the review can more specifically be

Table 3
Analysis of e-learning environment during Covid-19 pandemic.

Name of Paper	Reference No.	Observations	Views on e-learning enhancement
E-Learning during lock-down of Covid-19 pandemic: A global perspective	(Radha et al., 2020)	Pandemic made e-learning an integral part of school/college/university education	E-learning can improve self-learning skills of students and their academic performance
Online learning: A panacea in the time of COVID-19 crisis	(Dhawan, 2020)	Educational institutions have shifted focus from traditional classroom teaching methods to technology-assisted education	Changed educational environment brings new opportunities and chal-lenges for improved e-learning systems
Campus traffic and e-Learning during COVID-19 pandemic	(Favale et al., 2020)	Internet played a vital role in supporting educational process during pandemic	Internet robustness is important for successfully management of e-learning process
Pedagogical Consider-ations of E-Learning in Education for Development in the Face of COVID-19	(Ananga, 2020)	Demand and supply of educational content has changed due to increased internet use for learning	Institutions are widely exploring and adopting improved e-learning methods, especially in higher education
Current Trends in Education Technologies Research Worldwide: Meta-Analysis of Studies between 2015 and 2020	(Yildiz et al., 2020)	Educational institutions rapidly shifted to e-learning mode due to pandemic	Enhanced e-learning systems can positively impact student learning and student satisfaction
Challenges to online medical education during the COVID-19 pandemic	(Rajab et al., 2020)	E-learning systems should be made a more effective mechanism for education	Technology-related challenges and obstacles should be overcome to increase effectiveness of e-learning systems
Examining the moderat-ing effect of perceived benefits of maintaining social distance on e-learning quality during COVID-19 pandemic	(Saxena et al., 2021)	Pandemic affected student-satisfaction levels in e-learning systems	E-learning quality can be improved by focusing on Internet content, receptiveness, dependability, and assurance
An analysis of students' perspectives on e-learning participation–the case of COVID-19 pandemic	(Nikou and Maslov, 2021)	Pandemic awareness and challenges have directly affected student intention in e-learning systems	Efforts are required to make e-learning systems more useful and more adaptive to student needs
Impact of Technologies During COVID-19 Pandemic for Improving Be-havior Intention to Use E-learning	(Tawafak et al., 2021)	Extensive use of technology-aided e-learning systems during pandemic	Enhanced e-learning environments should enable students to develop technology-related skills for better academic performance
The role of e-learning in-frastructure and	(Garad et al., 2021)	E-learning infrastructure played vital role in	Improved e-learning systems require financial

Table 3 (*continued*)

Name of Paper	Reference No.	Observations	Views on e-learning enhancement
cognitive competence in distance learning effectiveness during the covid-19 pandemic		improving distance-learning effectiveness during pandemic	grants from government, teachers' trainings and workshops etc.
Impact of COVID-19 on achieving the goal of sus-tainable development: E-learning and educational productivity	(Wang et al., 2021)	Pandemic forced educational institutions world-wide to set up e-learning systems on war footing	E-learning systems can improve with enhanced focus on students, teachers, study plan, technology, and envi-ronment
Challenges of higher education related to e-learning in developing countries during COVID-19 spread: a review of the perspectives of students, instructors, policy makers, and ICT experts	(Zarei and Mohammadi, 2021)	E-learning marked a comprehensive response of the education system to the pandemic	Developed countries have more enhanced e-learning infrastructure than developing countries
The Development and Adoption of Online Learning in Pre-and Post-COVID-19: Combi-nation of Technological System Evolution Theory and Unified Theory of Acceptance and Use of Technology	(Qiao et al., 2021)	Institutions can transition from in-class to online education through widespread use of e-learning tools and technologies	Evolution and adoption of technology can foster e-learning environments for continuing education during and after pandemic

explained as follows:

- The paper acknowledges the noteworthy rise in the adoption of e-learning systems by educational institutions worldwide in recent years. The amalgamation of technology and educational content has paved the way for institutions to switch over to e-learning and other technology-assisted mechanisms for instructional purposes.
- Increased use of technology in 21st century has made it pertinent for educational systems to restructure their institutional mechanisms in tune with the changing times. For this, educational institutions depend greatly on researchers who can put forth new technology-assisted education models.
- EDM researchers in the past have proposed enhancements to e-learning systems. They have been using vari-ous techniques for mining valuable information from educational datasets, in order to understand and evaluate student behavior and student performance in e-learning settings.
- The paper points to the fact that the pandemic has dramatically changed the educational environments all over the world. It has disrupted the normal course of instructional mechanisms in educational institutions.
- The prolonged impact of the pandemic would prompt EDM researchers to study the use of new, advanced tech-niques that can help educational institutions enhance their e-learning system and make the learning process more adaptive to student needs.

The relevance of the review can also be highlighted by the fact that constructive dialogue, talks and discussions related to e-learning

systems in developed countries gained ground in 2020 and 2021, as is evident from Table 4 and Table 5. The tables, based on information obtained from LearnDash and Class Central sources, show the number of e-learning related conferences that were scheduled in US and Europe during these two years following the Covid pandemic.

4.2. | Implications for e-learning systems

EDM is one of the prominently emerging research fields of data mining, which has a proven role in education. Effective usage of online learning can improve the quality of educational resources while also allowing educators to plan lessons and students to widen their horizons. It enables educators to examine a student's particular needs and adjust classes to meet them. One significant advantage of using the internet for education is that it makes classes available even in remote settlements and rural locations where girls frequently experience educational disparities. Furthermore, the usage of the internet by students allowed them to continue their educational endeavors during the Coronavirus outbreak, which brought the world to a halt.

This review paper points to some of the major EDM application areas in e-learning over the past few years. It underlines the application of EDM techniques in the e-learning systems to achieve two broad objectives of e-learning:

(i) improving the quality of the teaching-learning process and (ii) ensuring that the learning process meets the needs of students. The Covid-19 has unsettled the global education industry, which has been hit really hard because of lockdowns. As a result of the pandemic, there has been a complete transformation of the education sector to an online mechanism globally. The uncertainties in education, attributable to the pandemic, have highlighted the significance and trustworthiness of e-learning methods. These methods are projected to expand further in the post-Covid years, owing to the projected development of new means of using digital technology for its effective integration into student education.

Hence, the main implication of this review for EDM research and e-learning is that it identifies some potential priority areas in e-learning, as illustrated in Table 6.

Table 4

E-Learning and training Conferences scheduled in 2020.

Name of the Conference	Start date	End Date	Location
In the USA			
Curation and Learning Lab	February 4	February 6	Saratoga Springs, NY
TechKnowledge Conference	February 5	February 7	San Jose, CA
ITC 2020 Annual eLearning Conference	February 9	February 12	Charleston, SC
Training 2020 Conference and Expo	February 24	February 26	Lake Buena Vista, FL
Learning Solutions and Realities 360	March 31	April 2	Orlando, FL
OLC Innovate	March 31	April 3	Chicago IL
ADT2020	May 17	May 20	Denver, CO
Learning DevChamp 2020	June 2	June 5	Salt Lake City, UT
Training Industry Conference and Expo	June 16	June 18	Raleigh, NC
WPCampus	July 15	July 17	New Orleans, LA
TechLearn Conference 2020	October 13	October 15	Austin, TX
DevLearn	October 21	October 23	Las Vegas, NV
WorldCamp US	October 27	October 29	St. Louis, MO
Slate Conference	November 11	November 13	Naperville, IL
OLC Accelerate	November 17	November 20	Lake Buena Vista, FL
In Europe			
Learning Technologies	February 12	February 12	London, UK
World of Learning Summit	May 15	May 15	London, UK
WorldCamp Europe	June 4	June 6	Porto, Portugal
World of Learning Summit	October 13	October 14	Birmingham, UK

Table 5

E-learning and training conferences scheduled in 2021.

Name of the Conference	Start date	End Date	Location/ Virtual
Future of Education Technology Conference Virtual	January 26	January 29	Virtual
Learning Leaders Online Forum	February 24	February 26	Virtual
Open Education Week 2021	March 1	March 5	Virtual
World Congress Virtual Educa	March 3	March 5	Virtual
Learnit Live: The Future of Learning is Now	March 8	March 12	Virtual
SXSW EDU	March 9	March 12	Virtual
Rutgers Online Learning Conference	March 15	March 16	Virtual
OLC Innovate 2021 Virtual Conference	March 15	March 19	Virtual
SXSW Conference	March 16	March 20	Virtual
Empower Webinar Week	April 6	April 8	Virtual
11th International Learning Analytics and Knowledge Conference	April 12	April 16	Virtual
EduTECH EUROPE 2021	April 28	April 29	Virtual
Learning Solution Conference and Expo	May 4	May 6	Orlando, FL
Educase Learning Initiative Annual Meeting	May 18	May 20	Virtual
Qatar Digital Learning Summit	June 2	June 3	Doha+Virtual
REMOTE: The Connected Faculty Summit by ASU	June 9	June 11	Virtual
London edtech week	June 14	June 21	London
The Learning Ideas Conference	June 16	June 18	Virtual
Learning @ Scale 2021/ EMOOCs 2021	June 22	June 25	Virtual
ICDE 2021	June 22	June 23	Rome
ISTE Digital Leadership Summit	June 27	June 30	San Antonio
Distance Teaching and Learning Conference	July 30	August 5	Virtual
ASU+GSV Summit: The Dawn of the Age of Digital Learning	August 9	August 11	San Deigo
ALT Annual Conference 2021	September 7	September 9	Virtual
16th European Conference on Technology Enhanced Learning	September 20	September 24	Bozen-Bolzano
Learning with MOOCs VIII	September 29	October 1	Antigua Guatemala
Open Education Global 2021	October 5	October 7	Nantes, France
EADTU I-HE2021	November 3	November 5	Bari
Innovate Learning 2021 Summit	November 9	November 11	Virtual
WEEF/GEDC 2021	November 15	November 18	Madrid
OEB Berlin	December 1	December 3	Berlin
2021 International Conference on Technologies in STEM 'LIVE'	December 14	December 15	Singapore

The above-mentioned priority areas should be explored by EDM researchers to help educational institutions make their e-learning programs more effective in future.

4.3. Broad application areas of EDM

There are numerous applications of EDM in e-learning for improving the teaching-learning process to create a better environment for meeting the students' requirements. Some of the well-recognized application areas of EDM are:

1. **Data analysis and visualisation**: Data analytics is the act of evaluating data sets to make decisions about the information they have, whereas data visualisation is the pictorial or graphical depiction of information and data.
2. **Providing feedback for supporting instructors**: Feedback is an essential component of the continuous learning and assessment

Table 6
Potential areas for EDM application to E-learning in future.

Name of Paper	Author	Suggestions for improving e-learning environment
Exploring factors that influence adoption of e-learning within higher education	(King and Boyatt, 2015)	Focus on infrastructure of educational institutions, skills/attitudes of staff-members, and other factors which can influence e-learning adoption
An exploratory case study of middle school student academic achieve- ment in a fully online virtual school	(Wolfinger, 2016)	Re-determining the role of teachers in facilitating fully online virtual learning for school students to improve student performance
A recommender model in e-learning environment	(Bourkoukou et al., 2017)	Devising new learning models to support personalized learning experiences for improving student performance and achievements
Educational Data Mining: A review of evaluation process in the e-learning	(Rodrigues et al., 2018)	Need to develop teaching-learning scenarios and other learning activities by focusing on behavioral research, interaction, collaboration, and performance
Time really matters: Understanding the temporal dimension of online learning using educational data mining	(Tang et al., 2019)	Important to shift to a new viewpoint on online teaching-learning process, by analyzing inter-related learning events
Online IS education for the 21st century	(He et al., 2014)	Need to study the training of teachers in designing, developing, teaching, and assessing online courses
Analysis of educational data mining	(Ahuja et al., 2019)	Understanding the challenges (like accuracy, functionality, and overheads, etc.) linked to extremely large educational datasets
Evaluation of Blackboard Learning Management System for Full Online Courses in Western Branch Colleges of Qassim University	(Alturise, 2020)	Focus on potential improvements in the application of e-learning systems to meet the changing needs of students
Exploring challenges of online education in COVID times	(Pandit and Agrawal, 2021)	Need to create effective e-learning ecosystem by focusing on collaborative student learning, skill in using digital technologies, knowledge of online-education tools, academic guidance etc.
Making the Transition to Virtual Methods in the Literacy Classroom: Reframing Teacher Education Practices	(Stoetzel and Shedrow, 2021)	Need to re-think and re-design lessons and assignments to integrate technology into learning materials to cope with unprecedented or unforeseen situations

process. Providing frequent and continual feedback to the instructors is an important way to improve learning achievement.

3. **Providing recommendations to students**: Recommender systems are used to produce personalised curricula, as well as to suggest individualised content on e-learning platforms, and it can also be used to forecast student achievement before they enrol for any higher educations.

4. **Student performance prediction**: Predicting student performance is essential, which aids in course selection and establishing appropriate future study programmes.

5. **Learner modelling**: A learner model, also known as a student model, is an organised depiction of the knowledge, misconceptions, and challenges of a learner. Learner models are built

from learner data, which is typically obtained by an intelligent tutoring system as a result of the learner's engagement with the tutoring system.

6. **Supporting the creation of student groups**: Grouping students refers to the employment of several methods to organise pupils in the classroom. They are usually organised to work in different ways during each lesson. The teacher frequently chooses groupings based on the activity type, the activity's goal, and the pupils.

7. **Adapting learning contents, sequences, and interfaces**: Adaptive learning is a teaching and learning system that aims to tailor classes, readings, practice exercises, and assessments to individual students based on their existing abilities and performances.

8. **Social network analysis**: Social network analysis is the practice of examining social systems using networks and graph theory. It defines networked systems in terms of nodes and the ties, edges, or links that connect them. Social network analysis techniques are used to examine patterns of relationships among people in groups. They are useful for evaluating persons or organisations' social structure and interdependencies (or work patterns).

9. **Studying relationships between teachers and learners**: A positive relationship between the teacher and the student in the classroom is defined as an endeavour to develop trust and respect for each other. This relationship could include getting to know the students better, giving them options, and motivating them to become better daily learners.

10. **Supporting teachers in concept map creation**: Concept maps are especially beneficial for visually learning students. Concept maps are an effective study approach because they help one to grasp the big picture: by beginning with higher-level concepts, they allow one to chunk material based on significant relationships.

11. **Assisting construction and reuse of learning content**: The knowledge structure is fostered by the learner's self- regulation and self-awareness. As a result, one must assist learners in acquiring important skills and information and provide tools and circumstances to enhance their ability to control their learning.

12. **Enhancing educational planning and scheduling**: Educational planning is a process in which each student engages in self-assessment, investigating and integrating academic and professional options, and making personal decisions for the present and future, whereas educational scheduling organizes students activities throughout the day, week, term or year.

13. **Learning Management System**: A learning management system is a software application that is used to manage educational courses, training programmes, materials, or learning and development activities. The concept of a learning management system evolved straight from e-learning.

14. **Management of dropouts and retention of students**: Dropout is defined as the termination of a programme, regardless of the reason, whereas retention refers to the student's continued participation in the programme after the original completion date.

Diverse EDM application areas can allow administrators and academicians to use data mining tools and participate in activities that can make data collection and processing more accessible to all EDM users. Examples include statistical and visualization tools that analyze social networks and their influence on learning outcomes and productivity.

5. Discussion

This review of EDM application to e-learning coincides with the widespread adoption of e-learning systems over the past few years, more specifically after the outbreak of the Covid-19 pandemic (Yu et al., 2022; Su et al., 2022; Shoib et al., 2022; Zhou et al., 2022).There is no denying

that e-learning has garnered unprecedented attention after the pandemic, which had an unsettling impact on almost all industries worldwide, with the education industry having been hit really hard. The pandemic led to a complete transformation of the education sector to an online mechanism globally. It has prompted academic planners to restructure the traditional classroom-learning systems and prepare for a much-required shift to smart education systems that involve increased use of technology tools and the Internet.

Against that backdrop, this review paper attempts to provide a general overview of how researchers have applied EDM techniques to propose improvements to e-learning systems in the past few years. This paper also highlights the need to upscale research efforts in this domain to meet the needs of the present-generation and future-generation students. The research papers selected for the review were divided into the following three groups to carry out a meaningful literature survey related to the use of EDM for improving e-learning systems — papers related to the application of EDM to e-learning in general, papers associated with EDM use for student performance prediction in e-learning; and papers related to the study of the impact of Covid-19 pandemic on the e-learning environment. The criteria for selecting articles for the first two groups were that the articles either involved using different EDM techniques in the context of e-learning or presented some specific approaches to improve e-learning systems. The research papers selected for the third group mainly focused on analyzing the e-learning environment during the Covid-19 pandemic. They included some pertinent suggestions for improving e-learning systems in the future so that the teaching-learning process should not be hampered due to unforeseen situations.

This review paper focused on answering the research questions in the Introduction section. The research ques- tions pertain to four important spheres concerning EDM use in e-learning — enhancement of e-learning systems, student performance/engagement prediction, the impact of the pandemic on e-learning, and potential e-learning fo- cus areas post-pandemic. Based on the outcome of the literature survey, it can be stated that, in answer to the first research question, researchers have applied EDM techniques to suggest improvements to the design of e-learning systems and to suit student needs better. Moreover, concerning the second research question, it is evident that student engagement and student performance in e-learning systems can be predicted by researchers using various techniques, such as classification, clustering, regression, and relationship mining, among several others. Concerning the third research question, it can be said that the Covid-19 pandemic has profoundly impacted the educational insti- tutions' approach toward e-learning (Iorember et al., 2022; Yao et al., 2022).Finally, in answer to the fourth research question, the review enlists some potential areas in e-learning on which educational institutions should direct their atten- tion in the post-Covid years.

However, despite the review paper's focus on EDM application to e-learning from the perspective of e-learning improvement, including past efforts and future potential, the review has certain limitations. The study presents only a general idea of EDM use in e-learning through a survey of some selected past research papers; it is not an all-inclusive effort. The main thought that served as the basis for paper selection was that the selected papers essentially involved the use of EDM techniques in e-learning, as anticipated from their title, abstract, keywords, or intro-duction. No specific search algorithms or techniques were used for paper selection; only certain search queries related to EDM for e-learning were used. For the selection of papers, the Google Scholar database was used. In addition, the main aim was to keep the study specific from the standpoint of a selection of papers pertaining only to the application of EDM techniques for enhancing e-learning. It underlined a conscious effort to keep other techniques and concepts — like Deep Learning, Machine Learning, Artificial Intelligence, Big Data, Learning Analytics, etc. — out of the scope of the review. This conscious decision behind the review has made it relevant for the present and future. The review can serve as a basis for more systematized and detailed surveys related to

EDM use in e-learning, specifically in terms of using some other database or complex search techniques involving the application of algorithms. Moreover, this review has also left the option open for similar reviews involving applying different techniques/concepts by researchers to suggest enhancements to e-learning for future-generation students, particularly with extensive use of technology and the pandemic impact in retrospection.

6. Open issues in educational data mining

The main objective of EDM research is to understand the factors which affect student learning in the modern-day online learning or e-learning systems. EDM researchers seek to understand student behaviors and conceptualize the new-age learning environments that can endorse the reinforcement of the education process outside the traditional classrooms. With researchers chiefly aimed at potential improvements in teaching-learning methods, there are several open issues in EDM. Some of the most prominent issues are:

- EDM is an iterative procedure of extracting useful information from large educational datasets — it involves the use of repetitive pro-cesses of hypothesis formulation, testing of hypothesis, and fine-tuning of results. Hence, for greater credibility of research in EDM, the iterative process of data mining should be illustrated by re-searchers in detail.
- It is difficult for EDM researchers to identify the extent to which the results of their studies pertaining to a specific learning scenario can be effectively transferred to other educational settings. Therefore, the contexts of research linked to data mining in education necessi-tate a comprehensive explanation by researchers.
- The application of conventional data mining algorithms to educa-tional attributes is not always possible because EDM researchers have to distill huge amounts of data which is a result of rapid data growth in educational environments. Consequently, EDM research requires the use of more complex sets of algorithms rather than conventional algorithms.
- In the case of educational findings, there is no mechanism for gauging the quality of insights provided by EDM researchers because they specifically try to discover the underlying models in educational data. As such, it is important that EDM researchers should clearly delineate an educational-data model as a representation of actual educational settings.
- There is an apparent perception that the anonymity of students can be compromised when cumulative summation of student data within an algorithm is allowed by educational institutions. It is, therefore, essential to change the perceptions linked to the understanding of student-identifying attributes associated with EDM research.

Overall, it is important to point out that the open issues in EDM can be addressed in the future with the help of cross-disciplinary ap-proaches, instead of focusing on one particular specialized approach. The use of different approaches can encompass various areas of proficiency and enhance the data-analysis process for EDM researchers. The open issues in EDM need to be addressed in a far-sighted manner, so that EDM research can help educational systems successfully overcome the challenges posed by fast-paced technological advancements in the 21st century.

7. Conclusion and future research directions

7.1. Conclusion

The review of EDM application to e-learning systems in this paper has highlighted that EDM is a prominently emerging research field that pivots around the use of diverse techniques to analyze educational datasets and develop new educational models. The introduction of

interactive e-learning methods has unfolded numerous opportunities for EDM to understand and evaluate the technology-assisted learning process in diverse contexts. The research-based understanding can subsequently enable academic planners to develop 'smart' and efficient educational systems which can support students as well as teachers.

This study has presented growth of published papers on e-learning over the last two decades, reviewed the pro- cess of data mining in education and also provided insights into the role of teachers in e-learning environment. In the present work, a comprehensive review of various EDM techniques based on the methodologies such as support vector machines, Naïve Bayes, K-means clustering, linear regression, cluster analysis, random forest, and multi-layer perceptron has been presented. According to the methodology-based taxonomy, the review presented the purpose, outcome, and technique of each problem and, along with them, presented a review and analysis of EDM. This systematic analysis has helped in understanding different methodologies for EDM so that the most suitable one can be selected.

This review coincides with the outbreak of Covid-19 pandemic, which has impacted the education sector like never before. The crisis is said to have emerged as a 'constructive disruptor' for the educational domain because it has augmented the role of technology in learning while disrupting classroom teaching. The pandemic has provided a unique opportunity for EDM researchers to focus on adapting the existing education system to futuristic learning. Owing to the pandemic, academic planners already have efforts underway to restructure the traditional classroom- learning structure and make a gradual shift to e-learning systems. The present study has also explored EDM applications in the current era. Furthermore, this research has also presented implications for e-learning systems and reviewed recent trends in e-learning based on previous research results.

Lastly the articles summarize and discusses the future research directions and challenges based on the previous research. Overall the proposed research is expected to help researchers understand the limitations and advantages of various EDM techniques and can help in contributing towards future development of methodologies related to e-learning system.

Based on the review, it is projected that research pertaining to EDM application to e-learning is bound to increase in the coming years. The global e-learning market is poised for steady growth in the post-Covid period, as indicated in Fig. 7. The figure, based on the information drawn from E-learning industry statistics and Research And Markets. com, shows that the size of the global e-learning market has increased tremendously since 2010 — from $32.1 billion in 2010, $107 billion in 2015, and approximately $250 billion in 2020. It is further set for an exponential increase over the next 4–5 years and is expected to reach upto $325 billion in 2025.

Finally, this review also underlines the anticipation that developers of online education platforms are likely to venture further into the 'Smart Education' arena after the pandemic. They are expected to launch improved e-learning features to enhance their platforms in line with the students' learning needs. (Fig. 8).

7.2. Future research directions

The future direction for research in the field of EDM application to e-learning would be to focus on the emerging aspects and factors that may impact the dynamic e-learning environment. With technology set to play a big role in education, particularly after Covid, it would be appropriate to undertake research efforts to make the learning process more 'need aligned' for students and help them achieve greater academic success. Some of the e-learning aspects which would necessitate the attention of EDM researchers in the future will be:

- Proposing re-design of lessons and assignments to integrate technology into the learning process
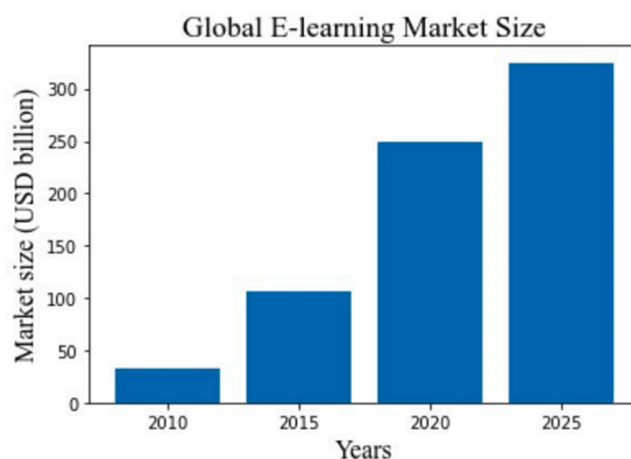

Fig. 8. Global E-learning market size.

- Analyzing student engagement and student satisfaction with e-learning programs
- Predicting student performance in fully online virtual learning environments
- Suggesting approaches that can make e-learning programs more value-oriented
- Evaluating the possible increase in first-time students accessing online programs in the post-Covid period.

To summarize, future research would aim at the use of EDM in e-learning to identify students with access to online learning after the Covid pandemic, propose models for more flexible study programs, recognize the need for student support, and explore the prospects of the realistic combination of classroom education and e-learning environments.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Funding details

There is no funding for this research work.

Conflict of interest

The authors declare that they have no conflict of interest.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Author statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript.

References

Abbas, J., 2020. The impact of coronavirus (SARS-CoV2) epidemic on individuals mental health: the protective measures of Pakistan in managing and sustaining transmissible disease. Psychiatr. Danub. 32 (3–4), 472–477.

Abbas, J., Aman, J., Nurunnabi, M., Bano, S., 2019. The impact of social media on learning behavior for sustainable education: Evidence of students from selected universities in Pakistan. Sustainability 11 (6), 1683.

Abd Elaal, S.A.E., 2013. E-learning using data mining. 21th Int. Conf. Chin. Res. J.

Abrioux, D., 2001. Converting to online course and program delivery: Global perspectives. Int. Rev. Res. Open Distrib. Learn. 1 (2).

Aguinis, H., Yu, L., Tosun, C., 2021. How to enhance scholarly impact: recommendations for university administrators, researchers and educators. Int. J. Contemp. Hosp. Manag.

Ahuja, R., Jha, A., Maurya, R., Srivastava, R., 2019. Analysis of educational data mining. Harmony Search and Nature Inspired Optimization Algorithms. Springer,, pp. 897–907.

Al Halbusi, H., Al-Sulaiti, K., Abbas, J., Al-Sulaiti, I., 2022. Assessing factors influencing technology adoption for online purchasing amid COVID-19 in Qatar: moderating role of word of mouth. Front. Environ. Sci. 1039.

Algarni, A., 2016. Data mining in education. Int. J. Adv. Comput. Sci. Appl. 7 (6), 456–461.

Ali, M.M., 2013. Role of data mining in education sector. Int. J. Comput. Sci. Mob. Comput. 2 (4), 374–383.

Altimari F., Plastina A.F., Cronin M.D., Servidio R., Caria M., Pedrazzoli A. Authoring tutored, adaptive e-courses in a personal learning environment: a dynamic syllabus and dynamic assembly approach. In: Proceedings of the World Congress on Engineering and Computer Science, vol. 1; 2012. p. 236–242.

Alturise, F., 2020. Evaluation of Blackboard Learning Management System for Full Online Courses in Western Branch Colleges of Qassim University. Int. J. Emerg. Technol. Learn. (iJET) 15 (15), 33–51.

Ananga, P., 2020. Pedagogical Considerations of E-Learning in Education for Development in the Face of COVID-19. Interna- tional J. Technol. Educ. Sci. 4 (4), 310–321.

Anderson, T., 2004. Teaching in an online learning context. Theory Pract. Online Learn. 273.

Anjewierden A., Kolloffel B., Hulshof C. Towards educational data mining: Using data mining methods for automated chat analysis to understand and support inquiry learning processes. In: International Workshop on Applying Data Mining in e-Learning (ADML 2007) Citeseer; 2007. p. 27–36.

Aparicio M., Bacao F., Oliveira T. An e-learning theoretical framework. An e-learning theoretical framework 2016;(1):292–307.

Appalla, P., Kuthadi, V.M., Marwala, T., 2017. An efficient educational data mining approach to support e-learning. Wirel. Netw. 23 (4), 1011–1024.

Aqeel, M., Rehna, T., Shuja, K.H., Abbas, J., 2022. Comparison of students' mental wellbeing, anxiety, depression, and quality of life during COVID-19's full and partial (smart) lockdowns: a follow-up study at a 5-month interval. Front. Psychiatry 13.

Arinto, P.B., 2016. Issues and challenges in open and distance e-learning: Perspectives from the Philippines. Int. Rev. Res. Open Distrib. Learn. 17 (2), 162–180.

Armellini A., Jones S. Carpe Diem: seizing each day to foster change in e-learning design. 2008;.

Ashraf, A., Khan, M.G., 2017. Effectiveness of data mining approaches to E-learning system: A survey. NFC IEFR J. Eng. Sci. Res. 4.

Azadi, N.A., Ziapour, A., Lebni, J.Y., Irandoost, S.F., Abbas, J., Chaboksavar, F., 2021. The effect of education based on health belief model on promoting preventive behaviors of hypertensive disease in staff of the Iran University of Medical Sciences. Arch. Public Health 79 (1), 69.

Baker, R., et al., 2010. Data mining for education. Int. Encycl. Educ. 7 (3), 112–118.

Baker, R., 2015. Big data and education. New York: Teachers College. Columbia University,.

Baker, R.S., Yacef, K., et al., 2009. The state of educational data mining in 2009: A review and future visions. J. Educ. - tional data Min. 1 (1), 3–17.

Baritchi A. Data mining and knowledge discovery. In: Business Intelligence in the Digital Economy: Opportunities, Limitations and Risks IGI Global; 2004.p. 35–47.

Bates, T., 2008. Transforming distance education through new technologies. Int. Handb. Distance Educ. 217–236.

Bennett, S., Agostinho, S., Lockyer, L., Harper, B., 2009. Researching Learning Design in Open, Distance, and flExible Learning: In- Vestigating Approaches to Supporting Design Processes and Practices. Taylor & Francis,.

Bharati M., Ramageri M. Data mining techniques and applications 2010;.

Bhardwaj B.K., Pal S. Data Mining: A prediction for performance improvement using classification. arXiv preprint arXiv:12013418 2012;.

Bhattacharyya, D.K., Hazarika, S.M., 2006. Networks, Data Mining, and Artificial Intelligence: Trends and Future Directions. Narosa Pub House.

Bourkoukou, O., El Bachari, E., El, Adnani, M., 2017. A recommender model in e-learning environment. Arab. J. Sci. Eng. 42 (2), 607–617.

Bousbia, N., Belamri, I., 2014. Which Contribution Does EDM Provide to Computer-Based Learning Environments? Educational Data Mining. Springer, pp. 3–28.

Brown, S., White, S., Power, N., 2015. Tracking undergraduate student achievement in a first-year physiology course using a cluster analysis approach. Adv. Physiol. Educ. 39 (4), 278–282.

Calvert, J., 2005. Distance education at the crossroads. Distance Educ. 26 (2), 227–238.

Campbell, J.P., DeBlois, P.B., Oblinger, D.G., 2007. Academic analytics: a new tool for a new era. EDUCAUSE Rev. 42 (4), 40.

Castillo-Merino, D., Serradell-López, E., 2014. An analysis of the determinants of students' performance in e-learning. Com. - Puters Hum. Behav. 30, 476–484.

Castro, F., Vellido, A., Nebot, A., Mugica, F., 2007. Applying data mining techniques to e-learning problems. Evolution of Teaching and Learning Paradigms in Intelligent Environment. Springer,, pp. 183–221.

Cleveland-Innes, M.F., Garrison, D.R., 2010. An Introduction to Distance Education: Understanding Teaching and Learning in a New Era. Routledge.

Cocea, M., Weibelzahl, S., 2009. Log file analysis for disengagement detection in e-Learning environments. Use Model. Use -Adapt. Interact. 19 (4), 341–385.

Daghestani, L.F., Ibrahim, L.F., Al-Towirgi, R.S., Salman, H.A., 2020. Adapting gamified learning systems using educational data mining techniques. Comput. Appl. Eng. Educ. 28 (3), 568–589.

Dhawan, S., 2020. Online learning: a panacea in the time of COVID-19 crisis. J. Educ. Technol. Syst. 49 (1), 5–22.

Dwivedi A., Dwivedi P., Bobek S., Zabukovšek S.S. Factors affecting students' engagement with online content in blended. learning. Kybernetes 2019;.

El Gourari A., Skouri M., Raoufi M., Ouatik F. The Future of the Transition to E-learning and Distance Learning Using Artificial Intelligence. In: 2020 Sixth International Conference on e-Learning (econf) IEEE; 2020. p. 279–284.

El-Sofany H., El-Haggar N. The effectiveness of using mobile learning techniques to improve learning outcomes in higher education 2020;.

Falakmasir M.H., Habibi J. Using educational data mining methods to study the impact of virtual classroom in e-learning. In: Educational Data Mining 2010 ERIC; 2010.

Favale, T., Soro, F., Trevisan, M., Drago, I., Mellia, M., 2020. Campus traffic and e-Learning during COVID-19 pandemic. Comput. Netw. 176, 107290.

Fu, Q., Abbas, J., Sultan, S., 2021. Reset the industry redux through corporate social responsibility: the COVID-19 tourism impact on hospitality firms through business model innovation. Front. Psychol. 6686.

Ganesh S.H., Christy A.J. Applications of educational data mining: a survey. In: 2015 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS) IEEE; 2015. p. 1–6.

Garad, A., Al-Ansi, A.M., Qamari, I.N., 2021. The role of e-learning infrastructure and cognitive competence in distance learning effectiveness during the covid-19 pandemic. J. Cakrawala Pendidik. 40 (1), 81–91.

Goyal, M., Vohra, R., 2012. Applications of data mining in higher education. Int. J. Comput. Sci. Issues (IJCSI) 9 (2), 113.

Grigorova K., Malysheva E., Bobrovskiy S. Application of data mining and process mining approaches for improving e-learning processes. In: 3rd International Conference on Information Technology and Nanotechnology; 2017. p. 25–27.

Grubišić, A., Žitko, B., Stankov, S., Sarić-Grgić, I., Gašpar, A., Tomaš, S., et al., 2020. A common model for tracking student learning and knowledge acquisition in different e-Learning platforms. J. E-Learn. Knowl. Soc. 16 (3), 10–23.

Gushchina, O., Ochepovsky, A., 2020. Data Mining Of Students' Behavior in E-Learning System. In: Journal of Physics: Conference Series, vol. 1553. IOP Publishing,, 012027.

Hamilton L., Halverson R., Jackson S.S., Mandinach E., Supovitz J.A., Wayman J.C. Using Student Achievement Data to Support Instructional Decision Making. IES Practice Guide. NCEE 2009–4067. National Center for Education Evaluation and Regional Assistance 2009;.

Han, J., Pei, J., Kamber, M., 2011. Data mining: concepts and techniques. Elsevier,.

Hanna, M., 2004. Data mining in the e-learning domain. Campus-wide Inf. Syst.

Haughey, M., Evans, T., Murphy, D., 2008. Introduction: from correspondence to virtual learning environments. Int. Handb. Distance Educ. 1–24.

He, W., Xu, G., Kruck, S., Online, I.S., 2014. education for the 21st century. J. Inf. Syst. Educ. 25 (2), 101–106.

Henrie, C.R., Halverson, L.R., Graham, C.R., 2015. Measuring student engagement in technology-mediated learning: a review. Comput. Educ. 90, 36–53.

Hill, T., Lewicki, P., Lewicki, P., 2006. Statistics: methods and applications: a comprehensive reference for science, industry, and data mining. StatSoft, Inc.

Injadat, M., Moubayed, A., Nassif, A.B., Shami, A., 2020. Systematic ensemble model selection approach for educational data mining. Knowl. -Based Syst. 200, 105992.

Iorember, P.T., Iormom, B., Jato, T.P., Abbas, J., 2022. Understanding the bearable link between ecology and health outcomes: the criticality of human capital development and energy use. Heliyon, e12611.

Jacob J., Jha K., Kotak P., Puthran S. Educational data mining techniques and their applications. In: 2015 International Conference on Green Computing and Internet of Things (ICGCIoT) IEEE; 2015. p. 1344–1348.

Janczewski L., Colarik A. Cyber warfare and cyber terrorism. IGI Global; 2007.

Jara M., Mohamad F. Pedagogical templates for e-learning. WLE Centre, Institute of Education, University of London; 2007.

Jie W., Hai-yan L., Biao C., Yuan Z. Application of educational data mining on analysis of students' online learning behavior. In: 2017 2nd International Conference on Image, Vision and Computing (ICIVC) IEEE; 2017. p. 1011–1015.

Jovanovic, M., Vukicevic, M., Milovanovic, M., Minovic, M., 2012. Using data mining on student behavior and cognitive style data for improving e-learning systems: a case study. Int. J. Comput. Intell. Syst. 5 (3), 597–610.

Karegar M., Isazadeh A., Fartash F., Saderi T., Navin A.H. Data-mining by probability-based patterns. In: ITI 2008–30th International Conference on Information Technology Interfaces IEEE; 2008. p. 353–360.

Kassab, M., DeFranco, J., Laplante, P., 2020. A systematic literature review on Internet of things in education: Benefits and challenges. J. Comput. Assist. Learn. 36 (2), 115–127.

Katz, Y.J., 2002. Attitudes affecting college students' preferences for distance learning. J. Comput. Assist. Learn. 18 (1), 2–9.

Kaur, H., Bathla, E.G., 2018. Student performance prediction using educational data mining techniques. Int. J. Future Revolut. Comput. Sci. Commun. Eng. 4 (12), 93–97.

Kausar, S., Huahu, X., Hussain, I., Wenhao, Z., Zahid, M., 2018. Integration of data mining clustering approach in the personalized E-learning system. IEEE Access 6, 72724–72734.

Khanna L., Singh S.N., Alam M. Educational data mining and its role in determining factors affecting students academic performance: A systematic review. In: 2016 1st India international conference on information processing (IICIP) IEEE; 2016. p. 1–7.

Khazaie, H., Lebni, J.Y., Abbas, J., Mahaki, B., Chaboksavar, F., Kianipour, N., et al., 2021. Internet addiction status and related factors among medical students: a cross-sectional study in Western Iran. Int. Q. Community Health Educ. p. 0272684X211025438.

King, E., Boyatt, R., 2015. Exploring factors that influence adoption of e-learning within higher education. Br. J. Educ. Technol. 46 (6), 1272–1280.

Ko, S., Rossen, S., 2017. Teaching Online: A Practical Guide. Routledge.

Koedinger K.R., D'Mello S., McLaughlin E.A., Pardos Z.A., Rose C.P. Data mining and education. Wiley Interdisciplinary. Reviews: Cognitive Science 2015;6(4):333–353.

Kumar, V., Chadha, A., 2011. An empirical study of the applications of data mining techniques in higher education. Int. J. Adv. Comput. Sci. Appl. 2 (3).

Larose, D.T., Larose, C.D., 2014. Discovering Knowledge in Data: an Introduction to Data Mining, vol. 4. John Wiley & Sons,.

Malhi, M.S., Iqbal, U., Nabi, M.M., Malhi, M.A.I., 2020. E-learning based on cloud computing for educational institution: Security issues and solutions. Int. J. Electron. Inf. Eng. 12 (4), 162–169.

McCarthy P., Boonthum-Denecke C. Applied natural language: identification, investigation and resolution. Information Science Reference, Pennsylvania 2011;.

Micah, A.E., Bhangdia, K., Cogswell, I.E., Lasher, D., Lidral-Porter, B., Maddison, E.R., et al., 2023. Global investments in pandemic preparedness and COVID-19: development assistance and domestic spending on health between 1990 and 2026. Lancet Glob. Health 11 (3), e385–e413.

Mitra, S., Acharya, T., 2005. Data Mining: Multimedia, Soft Computing, and Bioinformatics. John Wiley & Sons,.

Moradi, F., Ziapour, A., Abbas, J., Najafi, S., Rezaeian, S., Faraji, O., et al., 2021. Comparing the associated factors on lifestyle between type 2 diabetic patients and healthy people: a case-control study. Int. Q. Community Health Educ. p. 0272684X211022158.

Naidu S. Instructional designs for optimal learning. Handbook of distance education 2007;p. 247–258.

Nikou, S., Maslov, I., 2021. An analysis of students' perspectives on e-learning participation–the case of COVID-19 pandemic. Int. J. Inf. Learn. Technol.

Nisbet, R., Elder, J., Miner, G., 2009. Handbook of Statistical Analysis and Data Mining Applications. Academic press,.

Ong, C.S., Lai, J.Y., Wang, Y.S., 2004. Factors affecting engineers' acceptance of asynchronous e-learning systems in high-tech companies. Inf. Manag. 41 (6), 795–804.

Pandit, D., Agrawal, S., 2021. Exploring challenges of online education in COVID times. FIIB Bus. Rev. p. 2319714520986254.

Papamitsiou, Z.K., Economides, A.A., 2014. Learning analytics and educational data mining in practice: a systematic literature review of empirical evidence. J. Educ. Technol. Soc. 17 (4), 49–64.

Peña-Ayala, A., 2014. Educational data mining: A survey and a data mining-based analysis of recent works. Expert Syst. Appl. 41 (4), 1432–1462.

Prabha, S.L., Shanavas, A.M., 2014. Educational data mining applications. Oper. Res. Appl.: Int. J. (ORAJ) 1 (1), 23–29.

Priatna, T., Maylawati, D., Sugilar, H., Ramdhani, M., 2020. Key success factors of e-learning implementation in higher education. Int. J. Emerg. Technol. Learn. (iJET) 15 (17), 101–114.

Qiao, P., Zhu, X., Guo, Y., Sun, Y., Qin, C., 2021. The development and adoption of online learning in pre-and post-covid-19: combination of technological system evolution theory and unified theory of acceptance and use of technology. J. Risk Financ. Manag. 14 (4), 162.

Qureshi, R., AlManna, Y.M., Deshmukh, A.P., 2013. Big data: growing pressure on global storage by data created on social networking sites. Int. J. Comput. Sci. Manag. Res. 2 (3), 1876–1881.

Radha, R., Mahalakshmi, K., Kumar, V.S., Saravanakumar, A., 2020. E-Learning during lockdown of Covid-19 pandemic: a global perspective. Int. J. Control Autom. 13 (4), 1088–1099.

Rahmat, T.E., Raza, S., Zahid, H., Abbas, J., Sobri, F.A.M., Sidiki, S.N., 2022. Nexus between integrating technology readiness 2.0 index and students'e-library services adoption amid the COVID-19 challenges: implications based on the theory of planned behavior. J. Educ. Health Promot. 11.

Rajab M.H., Gazal A.M., Alkattan K. Challenges to online medical education during the COVID-19 pandemic. Cureus 2020;12(7).

Rakic S., Pavlovic M., Softic S., Lalic B., Marjanovic U. An evaluation of student performance at e-learning platform. In: 2019 17th International Conference on Emerging eLearning Technologies and Applications (ICETA); 2019. p. 681–686.

Rakic, S., Tasic, N., Marjanovic, U., Softic, S., Lüftenegger, E., Turcin, I., 2020. Student performance on an E-learning platform: mixed method approach. Int. J. Emerg. Technol. Learn. 15, 2.

Raval, K.M., 2012. Data mining techniques. Int. J. Adv. Res. Comput. Sci. Softw. Eng. 2 (10).

Rawat, K.S., Malhan, I., 2019. A hybrid classification method based on machine learning classifiers to predict performance in edu- cational data mining. Proceedings of 2nd International Conference on Communication, Computing and Networking. Springer,, pp. 677–684.

Ray, S., Saeed, M., 2018. Applications of educational data mining and learning analytics tools in handling big data in higher education. Appl. big data Anal. Springe 135–160.

Rodrigues, H., Almeida, F., Figueiredo, V., Lopes, S.L., 2019. Tracking e-learning through published papers: a systematic review. Comput. Educ. 136, 87–98.

Rodrigues, M.W., Isotani, S., Zarate, L.E., 2018. Educational Data Mining: a review of evaluation process in the e-learning. Telem. - atics Inform. 35 (6), 1701–1717.

Romero, C., Ventura, S., 2010. Educational data mining: a review of the state of the art. IEEE Trans. Syst., Man, Cybern., Part C. (Appl. Rev.) 40 (6), 601–618.

Romero, C., Ventura, S., De, Bra, P., 2004. Knowledge discovery with genetic programming for providing feedback to courseware authors. Use Model. Use -Adapt. Interact. 14 (5), 425–464.

Romero C., Ventura S., Pechenizkiy M., Baker R.S. Handbook of educational data mining. CRC press; 2010.

Russell, T.L., 2001. The no significant difference phenomenon: a comparative research annotated bibliography on technology for distance education. AL: Int. Distance Educ. Certif. Cent.

Sahoo S., et al. E-readiness and perception of student teachers' towards online learning in the midst of COVID-19 pandemic. Available at SSRN 3666914 2020;.

Sana B., Siddiqui I.F., Arain Q.A. Analyzing students' academic performance through educational data mining 2019.

Sangrà, A., Vlachopoulos, D., Cabrera, N., 2012. Building an inclusive definition of e-learning: An approach to the conceptual framework. Int. Rev. Res. Open Distrib. Learn. 13 (2), 145–159.

Saxena, C., Baber, H., Kumar, P., 2021. Examining the moderating effect of perceived benefits of maintaining social distance on e-learning quality during COVID-19 pandemic. J. Educ. Technol. Syst. 49 (4), 532–554.

Şen, B., Uçar, E., Delen, D., 2012. Predicting and analyzing secondary education placement-test scores: A data mining approach. Expert Syst. Appl. 39 (10), 9468–9476.

Shahiri, A.M., Husain, W., et al., 2015. A review on predicting student's performance using data mining techniques. Procedia Comput. Sci. 72, 414–422.

Shoib, S., Buitrago, J.G., Shuja, K., Aqeel, M., de Filippis, R., Abbas, J., et al., 2022. Suicidal behavior sociocultural factors in developing countries during COVID-19. L'encephale 48 (1), 78–82.

Shvets O., Murtazin K., Piho G. Providing Feedback for Students in E-Learning Systems: a Literature Review, based on IEEE Explore Digital Library. In: 2020 IEEE Global Engineering Education Conference (EDUCON) IEEE; 2020. p. 284–289.

Siemens, G., 2008. Learning and knowing in networks: Changing roles for educators and designers. ITFORUM Discuss. 27 (1), 1–26.

Silva, C., Fonseca, J., 2017. Educational data mining: a literature review. Eur. MENA Coop. Adv. Inf. - tion Commun. Technol. 87–94.

Silva, D., Randombage, P., Gankanda, W., Abeysekara, N., Edirisinghe, V., Chandrathilake, M., 2021. Evaluation of web-based distance education of medicine for undergraduates in Sri Lanka. Sri Lanka J. Obstet. Gynaecol. 43 (1).

Soni, V.D., 2019. IOT connected with e-learning. Vishal Dineshkumar Soni. IOT Connect. e-Learn. Int. J. Integr. Educ. 2 (5), 273–277, 2019.

Stoetzel, L., Shedrow, S., 2021. Making the Transition to Virtual Methods in the Literacy Classroom: Reframing Teacher Educa- tion Practices. In: Excelsior: Leadership in Teaching and Learning, 13, pp. 127–142.

Su, Z., McDonnell, D., Wen, J., Kozak, M., Abbas, J., Šegalo, S., et al., 2021. Mental health consequences of COVID-19 media coverage: the need for effective crisis communication practices. Glob. Health 17 (1), 1–8.

Su, Z., Cheshmehzangi, A., Bentley, B.L., McDonnell, D., Šegalo, S., Ahmad, J., et al., 2022. Technology-based interventions for health challenges older women face amid COVID-19: a systematic review protocol. Syst. Rev. 11 (1), 1–8.

Sumathi, S., Sivanandam, S., 2006. Introduction to Data Mining and its Applications, vol. 29. Springer.

Sun, P.C., Tsai, R.J., Finger, G., Chen, Y.Y., Yeh, D., 2008. What drives a successful e-Learning? an empirical investigation of the critical factors influencing learner satisfaction. Comput. Educ. 50 (4), 1183–1202.

Swan, K., 2020. Teaching and learning in post-industrial distance education. An Introduction to Distance Education Rout- ledge, pp. 67–89.

Tang, H., Xing, W., Pei, B., 2019. Time really matters: Understanding the temporal dimension of online learning using educational data mining. J. Educ. Comput. Res. 57 (5), 1326–1347.

Tawafak R., AlFarsi G., Jabbar J., Malik S.I., Mathew R., AlSidiri A., et al. Impact of Technologies During COVID-19 Pandemic for Improving Behavior Intention to Use E-learning 2021;.

Thai-Nghe, N., Drumond, L., Krohn-Grimberghe, A., Schmidt-Thieme, L., 2010. Recommender system for predicting student performance. Procedia Comput. Sci. 1 (2), 2811–2819.

Tomasevic, N., Gvozdenovic, N., Vranes, S., 2020. An overview and comparison of supervised data mining techniques for student exam performance prediction. Comput. Educ. 143, 103676.

Vai, M., Sosulski, K., 2011. Essentials of Online Course Design: A Standards-Based Guide. Routledge.

Vialardi-Sacín C., Shaftr L., Braver J., Ortigosa A. Recommendation in higher education using data mining techniques. Universidad de Cordoba; 2009.

Wan, S., Niu, Z., 2019. A hybrid e-learning recommendation approach based on learners' influence propagation. IEEE Transac- tions Knowl. Data Eng. 32 (5), 827–840.

Wang, X.Y., Li, G., Malik, S., Anwar, A., 2021. Impact of COVID-19 on achieving the goal of sustainable development: E-learning and educational productivity. Econ. Res. -Èkon. Istraživanja 1–17.

Wang, Y.S., 2003. Assessment of learner satisfaction with asynchronous electronic learning systems. Inf. Manag. - Ment. 41 (1), 75–86.

Whitley L.A. Educational data mining and its uses to predict the most prosperous learning environment 2018.

Wiliam, D., Thompson, M., 2008. Integrating Assessment With Learning: What Will it Take to Make It Work? Routledge.

Witten, I., Frank, E., Hall, M., Pal, C., 2017. Data Mining: Practical Machine Learning Tools and Techniques. Elsevier Inc.

Wolfinger S. An exploratory case study of middle school student academic achievement in a fully online virtual school. Drexel University; 2016.

Yao, J., Ziapour, A., Abbas, J., Toraji, R., NeJhaddadgar, N., 2022. Assessing puberty-related health needs among 10–15-year-old boys: a cross-sectional study approach. Arch. De. Pédiatrie 29 (4), 307–311.

Yildiz, E.P., Cengel, M., Alkan, A., 2020. Current trends in education technologies research worldwide: Meta-analysis of studies between 2015-2020. World J. Educ. Technol.: Curr. Issues 12 (3), 192–206.

Yu, S., Abbas, J., Draghici, A., Negulescu, O.H., Ain, N.U., 2022. Social media application as a new paradigm for business communi- cation: the role of COVID-19 knowledge, social distancing, and preventive attitudes. Front. Psychol. 13.

Zarei, S., Mohammadi, S., 2021. Challenges of higher education related to e-learning in developing countries during COVID-19 spread: a review of the perspectives of students, instructors, policymakers, and ICT experts. Environ. Sci. Pollut. Res. 1–7.

Zhang, D., Zhao, J.L., Zhou, L., Nunamaker Jr, J.F., 2004. Can e-learning replace classroom learning? Commun. ACM 47 (5), 75–79.

Zhang W., Qin S. A brief analysis of the key technologies and applications of educational data mining on online learning platform. In: 2018 IEEE 3rd International Conference on Big Data Analysis (ICBDA) IEEE; 2018. p. 83–86.

Zhou, Y., Draghici, A., Abbas, J., Mubeen, R., Boatca, M.E., Salam, M.A., 2022. Social media efficacy in crisis management: effective- ness of non-pharmaceutical interventions to manage COVID-19 challenges. Front. Psychiatry 1732.

ZoriÄ, A.B., et al., 2020. Benefits of educational data mining. J. Int. Bus. Res. Mark. 6 (1), 12–16.