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Bibliographic and Text Analysis of Research on Implementation of the Internet of Things to Support Education

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ABSTRACT

The Internet of Things (IoT) has pervaded practically all aspects of our lives. In this exploratory study, we survey its applications in the field of education. It is evident that technology in general, and, in particular IoT, has been increasingly altering the educational landscape. The goal of this paper is to review the academic literature on IoT applications in education to provide an understanding of the transformation that is underway. Using topic modeling and keyword co-occurrence analysis techniques, we identified five dominant clusters of research. Our findings demonstrate that IoT research in education has mainly focused on the technical aspects; however, the social aspects remain largely unexplored. In addition to providing an overview of IoT research on education, this paper offers suggestions for future research.

Keywords: Internet of Things (IoT), Education, Literature review, e-Learning, IS curriculum, Data mining

1. INTRODUCTION

With the evolution of technology, there have been tremendous improvements and innovations in the field of education. The fourth industrial revolution, known as Industry 4.0, inspired Education 4.0, which aims to enhance the use of digital technologies to introduce innovations in education that will enhance the scope of teaching and learning (Hariharasudan & Kot, 2018). The Internet of Things (IoT), artificial intelligence (AI), augmented reality (AR), and virtual reality (VR) are at the heart of the technological revolution that is transforming the educational landscape. Specifically, these technologies leverage and/or augment the advanced educational delivery that has been facilitated by portable devices such as laptops, smartphones, and tablets that support Internet connectivity. Various online and digital solutions that use IoT-like, sensor-based devices in the physical world to interface with cloud-based platforms have been widely used to replace or enhance traditional methods of instruction delivery.

Despite the rapid growth of IoT in education, the application of such advanced technologies is scarce in terms of usability and availability. Academic research in this field has seen a steep growth in recent years with more academic and non-academic researchers exploring the opportunities, challenges, and underlying themes. While we see a substantial increase in the implementation of IoT in education, there are still many challenges that need to be addressed in terms of skills, availability, affordability, infrastructure, and ethics. Identifying such gaps might help researchers and industry experts to understand the contributions made, and therefore allow them to focus more on future opportunities and challenges in this area.

Recently, due to the outbreak of the unprecedented COVID-19 pandemic, educational institutions have turned to digital technologies to provide online learning, to construct and enhance smart campus systems, and to build pedagogical capabilities that facilitate student performance and enrich the learning environment. The post-pandemic classroom continues to see a substantial increase in technology utilization for the efficient delivery of education (*CXOtoday News Desk*, 2021). So, unraveling the thematic areas in the current literature on IoT in education should be of value to the academic community and practitioners. Such an analysis would not only help us address the challenges and identify the contributions but also foresee what lies ahead.

This paper is an exploratory analysis of the current state of academic research on the applications of IoT in the education domain using topic modeling and bibliographic analysis. Our results reveal five clusters of major areas of research, which we label Wireless Network Technologies, Data, Security and Privacy, Technology-mediated Teaching and Learning, and Smart Educational Environments. Our paper makes four contributions to the existing literature. First, we provide insight into the social and technical perspectives related to IoT in education. Second, we use bibliometrics and text analysis to compare the thematic areas that have dominated the conversation in the field of IoT in education. Third, we provide insight into contributions in the current literature to guide educators to enhance technology-mediated teaching and learning. Lastly, our findings might serve as a roadmap for future researchers to explore the unaddressed issues and ultimately contribute to delivering solutions.

The remainder of this paper is organized as follows. The next section provides a background on education and the IoT in general. In Section 3, we describe the research methodology used in this study. Section 4 presents the discussion of the results using topic modeling. Section 5 provides contributions and implications. Section 6 summarizes this work. In the last section, limitations and directions for future research are presented.

2. THE IOT IN EDUCATION

The Internet of Things (IoT) refers to the networked interconnection of various objects that are equipped with intelligence and interact with each other involving the exchange of data generated by the devices (Xia et al., 2012; Zanella et al., 2014). IoT has been successfully implemented in areas such as smart cities; industries such as transportation, agriculture, and healthcare; smart energy, smart homes, and smart appliances (Nižetić et al., 2020). The IoT in education is a collection of components such as smart devices, information and communication technology devices, controllers, and human beings communicating with each other via the Internet and enabling cloud-based computing, big data solutions, and interactive experiences (Bagheri & Movahed, 2016). The real-time data generated by these devices helps the educational institutions evolve in terms of information technology (IT) infrastructure, security and privacy, and data management, as well as to gain valuable insights into the overall performance and experience of the stakeholders.

Academic institutions have initiated the utilization of IoT-based solutions to provide solutions in various settings. Curtin University, for instance, developed IoT and smart infrastructure to collect data and analyze student mobility and attendance (McRae et al., 2018). The IoT platform is not confined just to improving the learning experience of the students but also to enhancing the campus support systems, including energy management, campus security, space utilization, and operations. For example, the University of San Francisco implemented an IoT-based surveillance system to enhance safety and security on campus (*University Improves Access Control in Residence Hall*, 2021).

IoT implementation in the educational domain has not only provided enhanced solutions to problems in the traditional classroom but has also introduced new methods of engagement. IoT has been either applied or proposed in several areas of education such as IoT-based smart classrooms (Mahmood et al., 2019), smart campuses (Majeed & Ali, 2018), energy management systems (Mataloto et al., 2019), and cloud-based solutions (Faritha Banu et al., 2020).

Educational institutions have developed new opportunities for IoT usage to enhance learning. For example, Chicangana et al. (2019) presented the Orgatronics project, providing a videogame incorporating game-based system with IoT technology for learning about biological cells and the functioning of their organelles in biology. Ali et al. (2017) proposed an IoT-based Flipped Learning Platform (IoTFLiP) for Case-Based Learning (CBL) to improve medical students' academic and practical experiences. In vocational education and training, the adoption of IoT helps students prepare for working life and provides a safer education environment and self-directed learning (Vihervaara & Alapaholuoma, 2017).

The dynamics of the IoT, in general, have been studied in diverse domains by previous researchers to identify key factors and underlying patterns. Our study focuses on the implementation of the IoT in education by using topic modeling and keyword co-occurrence analysis to analyze the underlying patterns of research on the IoT in education. With supporting results, we identify some opportunities, challenges, and research gaps in the current literature on IoT-based education with both technical and social perspectives. We also identify existing solutions to enhance education delivery that are discussed by researchers in the current literature. Our research, in turn, can serve as a guide to educators in implementing an appropriate digital solution and a roadmap for future research.

3. RESEARCH METHODOLOGY

3.1 Data Collection

We conducted a keyword search of the Web of Science (WoS), considered a leading database for bibliometric and review articles, to retrieve abstracts of articles related to the IoT in the education domain. We used WoS because it is multidisciplinary and more current (Jacsó, 2005) and focuses on fields such as science, technology, social sciences, arts, and humanities (Falagas et al., 2008). WoS provides an option that searches the title, abstract, author keywords, and keywords plus fields of an article simultaneously, and fetches the articles that match with the search string. This way of retrieving data is appropriate for our study because it allows us to match our search string with the article keywords, thus, obtaining more relevant data for keyword co-occurrence analysis. Subsequently, the title and abstract of the retrieved articles were used to perform topic modeling since they generally provide a thematic focus and summary of each paper. We used the keywords of the retrieved articles for the keyword co-occurrence analysis using VOSviewer. We used the document type filter in WoS to select "Articles" only. With this setting, the search string (("IoT" or "Internet of Things") and ("education" or "school" or "online learning" or "university" or "e-Learning")) extracted a total of 693 articles, which were published between 2011 and 2020. For the data cleaning process, we manually screened the dataset to remove articles that were not relevant to our study, yielding 326 articles. The basis of article elimination is listed in Table 1.

Criteria for Inclusion of Articles	1. IoT technology-mediated learning 2. Design & development of learning & teaching platforms based on IoT technologies 3. Devices, wearables & sensors for IoT facilitated learning and/or Smart Campus implementation 4. Data collection, processing & analytics of sensor data in educational institutions 5. Privacy & security of data in educational institutions 6. Wireless sensor networks, RFID & ICT in the education context 7. Big data, cloud computing, fog computing, AR, VR, AI & data analytics implementation in education in the context of IoT 8. Challenges & enhancements in the implementation of IoT in education
Criteria for Exclusion of Articles	1. Articles that are not used in the education context 2. Articles that mention the word "education" as part of IoT definition 3. Data with missing abstract/title

Table 1. Inclusion and Exclusion Criteria for Data Cleaning

After cleaning the data, we obtained a list of journals whose articles appear in our dataset. Figure 1 lists journals in which at least 3 articles were found. IEEE Access contained the most with 20 articles, Sensors contained 13 articles, Sustainability contained 12 articles, Applied Sciences contained 8 articles, and so on.

We performed exploratory data analysis to summarize the key features and determine the underlying details of the data. Figure 2 represents the evolution of studies related to the IoT in education over the past 10 years. Based on this figure, we observe that the IoT in education emerged as a prevalent publication topic starting in 2017.

Figure 3 shows the frequency distribution of keywords that are present in each article for keywords that occurred in a minimum of 2 articles. Some of the most discussed areas include technical aspects such as big data, cloud computing, smart campus, and industry 4.0.

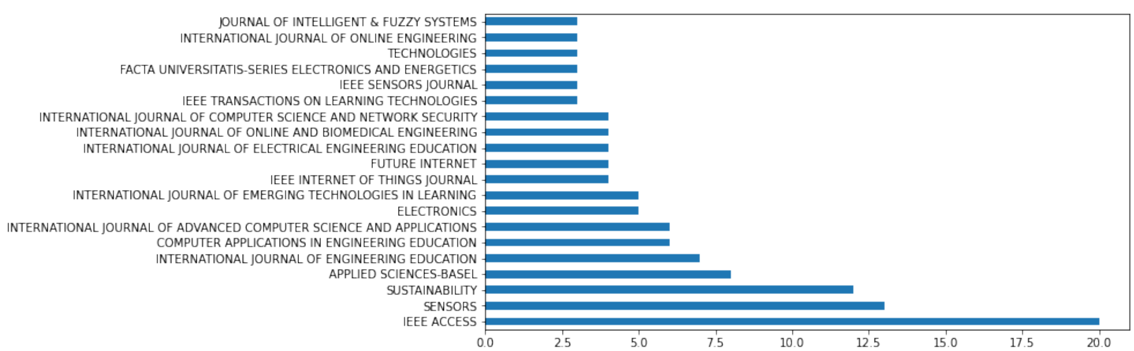

Figure 1. Frequency Distribution of Journals Appeared in Dataset

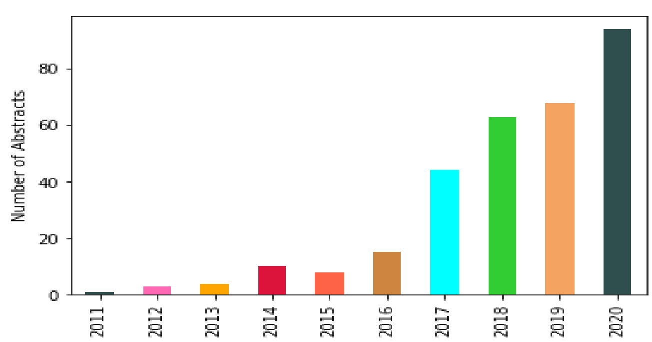

Figure 2. IoT in Education Articles Published Per Year

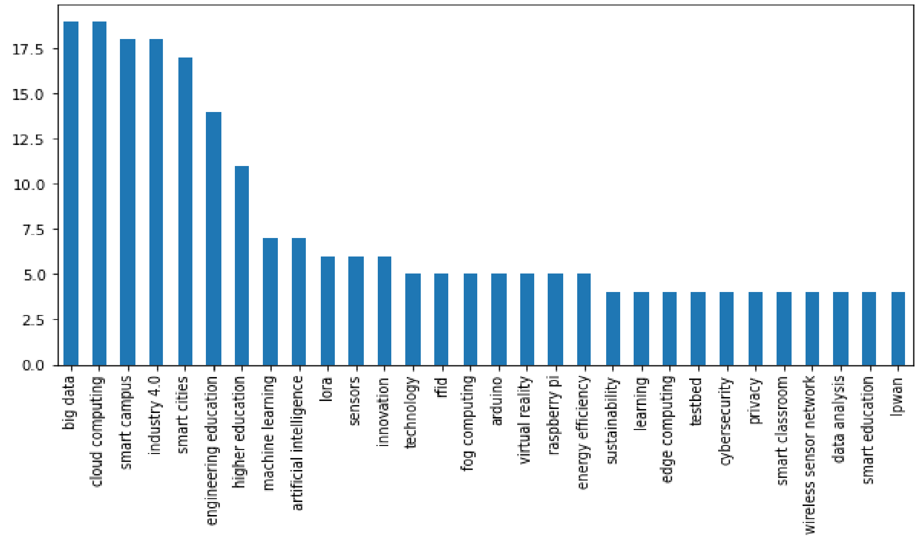

Figure 3. Frequency Distribution of Keywords

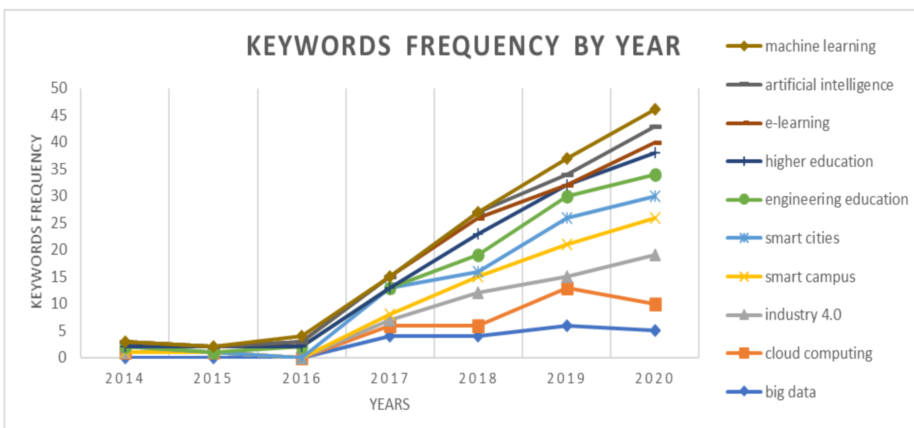

Figure 4. Keyword Frequency Across Years

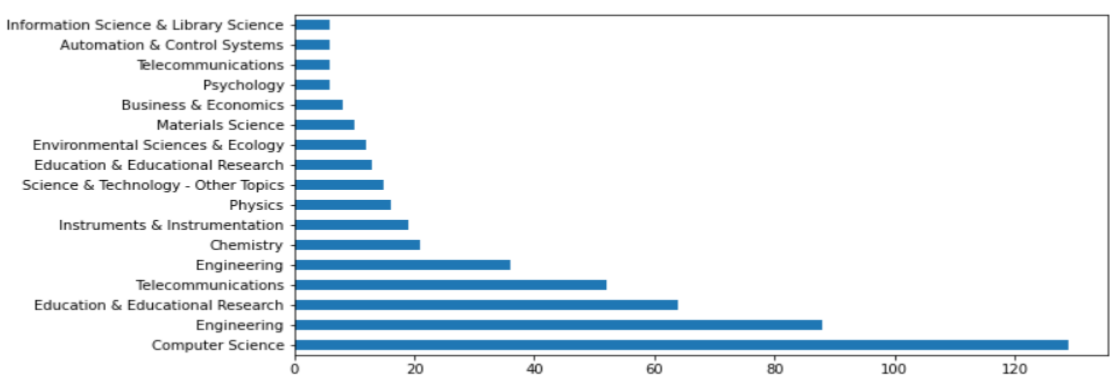

Figure 5. Number of Articles in Research Areas

Figure 4 depicts the frequency of keywords over time and their respective trends. The frequency diagram illustrates that the most common aspects the researchers studied are machine learning, artificial intelligence, e-Learning, and higher education. Topic modeling approaches that will be discussed in subsequent sections will help us understand these trends more clearly.

Figure 5 shows the number of articles in various research areas such as Computer Science, Engineering, Education and Educational Research, and Telecommunications. By analyzing the trend of the number of articles in each research area, we can understand the major areas in which research related to IoT in education has been focused over the years.

3.2 Topic Modeling
Topic modeling is a suitable technique for analyzing huge volumes of data. For example, topic modeling is used in natural language processing to discover the latent topic structure in a collection of documents (Blei, 2012). This approach helps organize and summarize the text corpus to facilitate extraction of useful information. The most three popular topic modeling algorithms are Latent Dirichlet Allocation (LDA), Latent Semantic Analysis (LSA), and Non-negative Matrix Factorization (NMF).

LDA uses the hidden topics in the data to create a probability distribution of topics and words and makes allocations based on the distribution (Blei et al., 2003). LDA is relevant when the documents hold multiple topics (Lee et al., 2010). LSA is a matrix-based technique where each cell of the matrix represents the frequency with which the term on the row appears in the context indicated by the column (Landauer et al., 1998). NMF is an unsupervised learning algorithm that performs dimensionality reduction and retains the information necessary to retrace the original data through feature reduction (Lopes & Ribeiro, 2015).

In our study, we used all three to see whether the combined outputs of three algorithms provide insights that would be missing if we used just one of the methods. To compare results from different topic modeling algorithms, we used each algorithm several times but with a different number of topics such as 5, 10, 15, and 20 topics. The results were further compared to find similarities and identify the most meaningful result. Eventually, we agreed that LDA provided the best results due to the quality and interpretability of topics and selected that algorithm to perform topic modeling.

To prepare the data for LDA, we converted data to lowercase and deleted digits, punctuations, and noise. The last step of data preprocessing was to lemmatize the data because it provided more relevant documents. Lemmatization involves looking for the words' synonyms, and therefore provides better results (Balakrishnan & Lloyd-Yemoh, 2014).

One of the model parameters for LDA is the number of topics, which is often difficult to determine (Zhao et al., 2015). A very high number of topics could result in noisy results that may be hard to interpret, while a very low number of topics may fail to uncover topics that are more specific or nuanced. In Figure 6, we illustrate a coherence graph that we used to determine the number of topics. It indicates that our final corpus consisted of 33 dominant topics. Hence, we extracted 33 topics using Python's Gensim for our further analysis. Gensim is flexible and suitable for advanced implementations as it allows the user to modify multiple parameters. After careful analysis, we eliminated two topics due to the lack of clarity in the topics. We identified five dominant categories across these 31 topics based on the similarities and overlapping among them. Finally, using the probability distribution of documents across the topics, we identified five relevant articles that contributed the most to each of the topics, resulting in a total of 155 articles. We read the articles to confirm each article's contribution to each topic and evaluated the similarities among these topics.

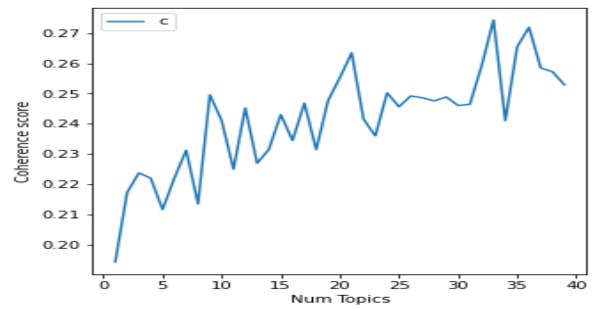

Figure 6: Coherence Scores for Various Topic Numbers

3.3 Keyword Co-occurrence Analysis
To perform Keyword Co-occurrence Analysis, we used a software tool called VOSviewer (www.vosviewer.com), which has been widely used for bibliometric mapping and visualization of keywords to understand scientific domains (Van Eck & Waltman, 2011). This tool and the keywords field of our dataset were used to generate a network of keywords where each node represents a keyword and a link between them represents the co-occurrence of the pair of words. In this study, we used full counting as the counting method and 4 as the minimum number of occurrences of a keyword to obtain the keyword mapping in VOSviewer. Of the total 1483 keywords, 79 keywords met the threshold yielding 5 clusters of keywords.

4. RESULTS

4.1 Topic Modeling
We identified five dominant clusters from the 31 topics extracted through the topic modeling. These clusters include Wireless Network Technologies, Data, Security and Privacy, Technology-mediated Teaching and Learning, and Smart Educational Environments. Further analysis reveals that there is overlap among the clusters. Instead, multiple research areas are located at the crossroads of these clusters. For instance, several research studies focused on fog computing involving aspects of data handling and security.

4.1.1 Topic Cluster 1: Wireless Network Technologies. IoT infrastructure involves smart sensors and actuators for remote information collection, data transmission, and interactions with other entities of the system. Based on our analysis, the major topics in this cluster focus on the implementation of various wireless network technologies to provide smart campus solutions, facilitate IoT-mediated learning, optimize performance and implementation costs, and address safety issues. Some common keywords associated with this cluster are network, cloud, sensor, communication, data, performance, and device.

Radio-frequency identification (RFID) is a major technology used in IoT deployment. For example, RFIDs have been used in library monitoring systems to monitor books in real-time (Bayani et al., 2018), and to track buses in school transportation systems (Raad et al., 2020). Researchers also focused on wireless network technologies such as Long-Range Wide-Area Network (LoRaWAN), a fog computing-based architecture, for connecting IoT nodes to support "physically distributed, low-latency and location-aware applications" on a university campus (Fraga-Lamas et al., 2019). This cluster overlaps with the Data and the Smart Educational Environments clusters.

Wireless network technologies play a significant role in facilitating IoT-based learning for students. Some implementations include the use of Bluetooth beacons to enhance the learning and teaching experiences (Mcdonald & Glover, 2016), as well as real-time bio-signal processing that helps teachers provide feedback to students by monitoring them in real-time (Kim, 2018).

4.1.2 Topic Cluster 2: Data. The application of the IoT in education generates enormous amounts of data related to students, courses, university campuses, and administrations. This data is generated and transmitted by various means and is generally heterogeneous in nature. Therefore, it is important to understand the methods and techniques for the collection, storage, processing, and analysis of such data. It is also important to create approaches for better data quality, privacy, and security. Some common keywords in this cluster are information, data, cloud, big data, approach, and knowledge.

Education IoT applications generally use wearables, mobile devices, sensors, audio and video devices, social media, and other smart campus equipment to collect data. Research related to data collection includes topics such as intelligent sensing, audio, and video data collection in the implementation of a music teaching assistant platform (Li, 2019), wearables and sensors in the implementation of an IoT-based exercise improvement system (Kang et al., 2019), and real-time data collection in Building Information Modeling (BIM) (Pavón et al., 2020). This area overlaps with Wireless Network Technologies and Smart Educational Environments.

Researchers focused on efficient techniques to handle and monitor the data generated from various sources. For example, a big data framework for smart campus data monitoring (Villegas-CH et al., 2019a), information integration to process big data (Chen, 2020), data quality assessment (Gilman et al., 2020), and a hybrid data storage infrastructure that enables Business Intelligence and Analytics of the data (Moscoso-Zea et al., 2019). Researchers also conducted studies to develop ways to analyze and draw insights from this data. Study topics include data mining analysis to predict the factors that affect the performance of a high school basketball team (Lee et al., 2020), and using a quantum computing framework to assess student performance (Bhatia & Kaur, 2020).

Privacy and security of personal information and other confidential data on a university campus are one of the critical aspects of IoT implementation. This cluster also involves studies that use blockchain technology to protect user data in the cloud (Villegas-CH et al., 2020). Thus, this research area partially overlaps with the Security and Privacy cluster.

4.1.3 Topic Cluster 3: Security and Privacy. Information Security and Privacy are crucial factors in the implementation of IoT in the education field. Data in the education field involves individual confidential data such as identity, social security number, residential address, and identity information. These are extremely sensitive data, and it is particularly important to make sure adequate security and privacy protection are provided. Any security breach could disclose a student's personal information related to an individual's medical record, family financial background, or any other confidential information (Gul et al., 2017). Due to the massive amounts of data generated, it becomes difficult to identify which data needs to be protected (Yang, 2012). A significant amount of research has been conducted on security and privacy in recent years.

Researchers have suggested frameworks to enhance security in IoT platforms. Qureshi et al. (2021) proposed a Secure system for the Internet of Schools Things (S-IoST) as a security solution for smart schools using 5G, cloud, and advanced analytics services. Researchers in this cluster have also focused on providing information security using blockchain technology in distance and blended learning environments (Glushkova et al., 2019), implementing fog computing technologies for better privacy and security (Adel, 2020), and providing security in a ubiquitous context-aware learning setting (Shapsough & Zualkernan, 2020). Some common keywords that appear in this cluster include data, blockchain technology, virtual, wireless, and network. This area overlaps with Data and Wireless Network Technologies clusters.

4.1.4 Cluster 4: Technology-mediated Teaching and Learning. As state-of-the-art computer and communication technologies have been developed, institutions of higher education focused on designing efficient ways to support both intellectual and practical learning experiences for students. This cluster includes the broad category of technology-mediated teaching and learning where IoT technologies are implemented to provide better learning experiences for the students. Some common keywords that appear in this cluster include distance, smart, teaching, develop, course, classroom, sensor, mobile, communication, virtual, and evaluation. The topics discussed in this cluster overlap with all the previously discussed clusters.

Researchers have focused mainly on wearables, interactive systems, virtual reality, AI solutions, various digital platforms, and e-Learning platforms, along with design guidelines for the development of these platforms. For example,

Skrimponis et al. (2020) proposed a cloud and wireless networking-based educational platform toolkit (COSMOS educational toolkit) to enhance middle and high school STEM education. Taamallah and Khemaja (2015) proposed integrating e-Learning models with IoT to provide pervasive (mixture of virtual and physical environments) learning experiences to enhance the quality of learning and teaching. In addition, a supportive framework for the implementation of smart educational tools and learning management systems (Iqbal et al., 2020), and IoT-based technology-enhanced learning in Computer Science and Engineering (Charlton & Avramides, 2016) were introduced by researchers.

Recent technological advancements in the field of VR and AR have opened opportunities for universities to provide better solutions. Ding et al. (2020) proposed a college physical education system based on IoT and virtual reality. Kaplan and Haenlein (2019) presented a study of the implementation of AI technologies to provide solutions including virtual teaching assistants, Robo-teachers, and AI-based career services to enhance student engagement.

Such technologies have enabled universities to implement remote and virtual labs. Asraf et al. (2018) demonstrated an interactive virtual lab to facilitate the student learning process through visualization and simulation. Cvjetkovic (2018) proposed and implemented Pocket Labs, allowing students to perform experiments with the equipment at any time and from anywhere. Robles-Gómez et al. (2020) implemented a virtual remote laboratory that is hosted on the cloud and integrated into a cyber security project.

4.1.5 Topic Cluster 5: Smart Educational Environments. This cluster includes research related to the design, development, and implementation of smart campus solutions using IoT technologies such as sensors, devices, and wireless networks. The Smart Educational Environments cluster also encompasses techniques such as big data and cloud computing. Examples include IoT-based laboratory environment quality monitoring in indoor spaces (Marques & Pitarma, 2019), a cloud-based IoT intelligent car parking system for university campuses (Ji et al., 2014), and a smart university stadium to provide improved safety, experience, and efficiency (Panchanathan et al., 2017). The most frequent keywords in this cluster are smart, environment, tool, real, knowledge, data, energy, classroom, and platform.

The topics included in this cluster overlap with the other clusters discussed earlier. For example, Gonzalez-Amarillo et al. (2020) implemented a smart lighting system for universities where lighting is automatically provided based on the sensor's real-time data about the number of people present in an indoor environment. Badshah et al. (2019) proposed a sensor-based smart security framework for educational institutions to provide on-premises security. Lu et al. (2021) presented a study to extract typical occupancy schedules from social media and used this data to improve hourly energy usage prediction in a university museum.

Smart campus solutions are implemented to enhance the student learning experience using techniques such as a smart classroom to mediate online physical education classes during the COVID-19 situation (Lu, 2020), flipping a classroom using an intelligent tutoring system (Hafidi & Lamia, 2018), real-time data logging, and an online curve fitting system using Raspberry Pi to enable students to fit experimental data to various mathematical functions (Wong et al., 2020).

Researchers also focused on the importance of performance measurement of various aspects of IoT implementation of IoT to support education. Alrashed (2020) provided a list of key performance indicators for smart campuses, allowing management to monitor their implementation. Romero-Rodríguez et al. (2020) studied the acceptance of smart campus solutions by university professors depending on the performance and conditions of the system and emphasized the need for further research to support virtual learning in situations such as COVID-19. Table 2 summarizes some of the examples of Campus/University-based projects discussed in each of the clusters.

Cluster	Campus/University Projects	Results	Citation
Wireless Network Technology	Track Buses in School Transportation Systems	The system provided access to safety records of bus drivers and protected students from infringements.	Raad et al., 2020
	LoRaWAN Fog Computing-based Architecture for Smart Campus	This paper provided guidelines to designers and developers of smart campuses and made the LoRaWAN network easy to deploy and research in smart campuses.	Fraga-Lamas et al., 2019
	IoT-Based Library Automation and Monitoring System	This paper found that using IoT-based library management provides global linking of libraries, better human data organization, and knowledge access.	Bayani et al., 2018
	Wireless Video Surveillance Systems	This paper showed that an optimized video surveillance system can effectively track multiple cameras in a wide-area surveillance scene, improve tracking and surveillance performance, and satisfy the needs of smart campus construction.	Zhou et al., 2020
Data	Real-time Data Collection Building Information Modeling (BIM)	BIM model and big data databases enhanced educational management and allowed the staff to efficiently manage the availability of large spaces along with the building or cleaning protocols.	Pavón et al., 2020
	Big Data Framework for Smart Campus Data Monitoring	The applied big data framework guaranteed high availability and scalability during energy monitoring.	Villegas-CH et al., 2019a
	Data Quality Assessment	This paper discussed a long-term real-world IoT deployment experience at a university campus and includes the challenges faced and lessons learned.	Gilman et al., 2020
	Student Performance Evaluation System	This paper concluded that introducing IoT in engineering education enhances the student learning experience. Conclusions were based on student performance evaluations using education data mining algorithms and student academic datasets.	Verma et al., 2017

Security & Privacy	Secure System for the Internet of Schools Things (S-IoST)	This paper proposed the S-IoST system as a security feature based on advanced data analytics services.	Qureshi et al., 2021
	Fog Computing for Privacy and Security	This paper found that fog computing provides efficient control over the privacy concept so that it easily manages the data within the system.	Adel, 2020
	Blockchain Technology	This paper presented an electronic school diary using Blockchain technology to provide support to students in the learning process and to ensure the reliability and security of storage of sensitive information.	Glushkova et al., 2019
Technology-mediated Teaching and Learning	Cloud & Wireless Networking-based Educational Platform	This paper proposed a program to improve teaching and learning in the STEM curriculum to gain wireless communications knowledge and developed the COSMOS Educational Toolkit.	Skrimponis et al., 2020
	Pervasive Learning	This paper showed new opportunities for both learners and teachers using e-Learning standards with IoT to design complex learning scenarios and keep track of students' pervasive learning experiences.	Taamallah & Khemaja, 2015
	VR Solutions	This paper showed that a VR system of physical education in universities can strengthen the teaching level, application, and promotion effects.	Ding et al., 2020
	AI-based Solutions	This paper presented a framework that helps universities, corporations, and governments with the implications of AI.	Kaplan & Haenlein, 2019
	Virtual Remote Labs	This paper found that students' attitudes positively affect their intention to use the Virtual Remote Laboratory (ViRe-Lab) and that their perception of the its usefulness positively influences their intention to use the ViRe-Lab.	Robles-Gómez et al., 2020
Smart Educational Environments	Energy Management System	This paper showed that the evaluation of the proposed LoBEMS (LoRa Building and Energy Management System) platform resulted in 20% energy savings.	Mataloto et al., 2019
	Environmental Quality Management for Indoor Laboratory Conditions	This paper found that the proposed system based on IoT supported meaningful indoor environment quality (IEQ) supervision solutions and enhanced living environments and occupational health by providing temperature, relative humidity, barometric pressure, and qualitative air quality supervision for both school and lab scenarios.	Marques & Pitarma, 2019
	Car Parking System for Smart Campus	This paper proposed an intelligent car parking system and a sample car parking service on a University campus to provide the best available parking lot information to users.	Ji et al., 2014
	Smart Stadium	This paper proposed the Smart Stadium for improved safety, fan engagement, efficiency, and convenience for wait times.	Panchanathan et al., 2017
	Sustainable Smart Campus	This paper found reliable and efficient solutions for the implementation of an intelligent environment based on sustainability using IoT technologies in smart campuses.	Villegas-CH et al., 2019b

Table 2. Examples of University-Based Projects in Current Literature

4.2 Keyword Co-occurrence Analysis

To validate our findings, we used VOSviewer as discussed in section 3.3. The VOSviewer extracted a total of seven clusters. We dropped two clusters that contained only three keywords. Figure 7 presents the network diagram from the keyword co-occurrences analysis along with the overlapped topic modeling results. It is evident that the cluster organization is consistent with our analysis using the topic modeling approach. Based on these results, we identified Wireless Network Technologies, Data, Security and Privacy, Technology-mediated Teaching and Learning, and Smart Educational Environments as the dominant research areas.

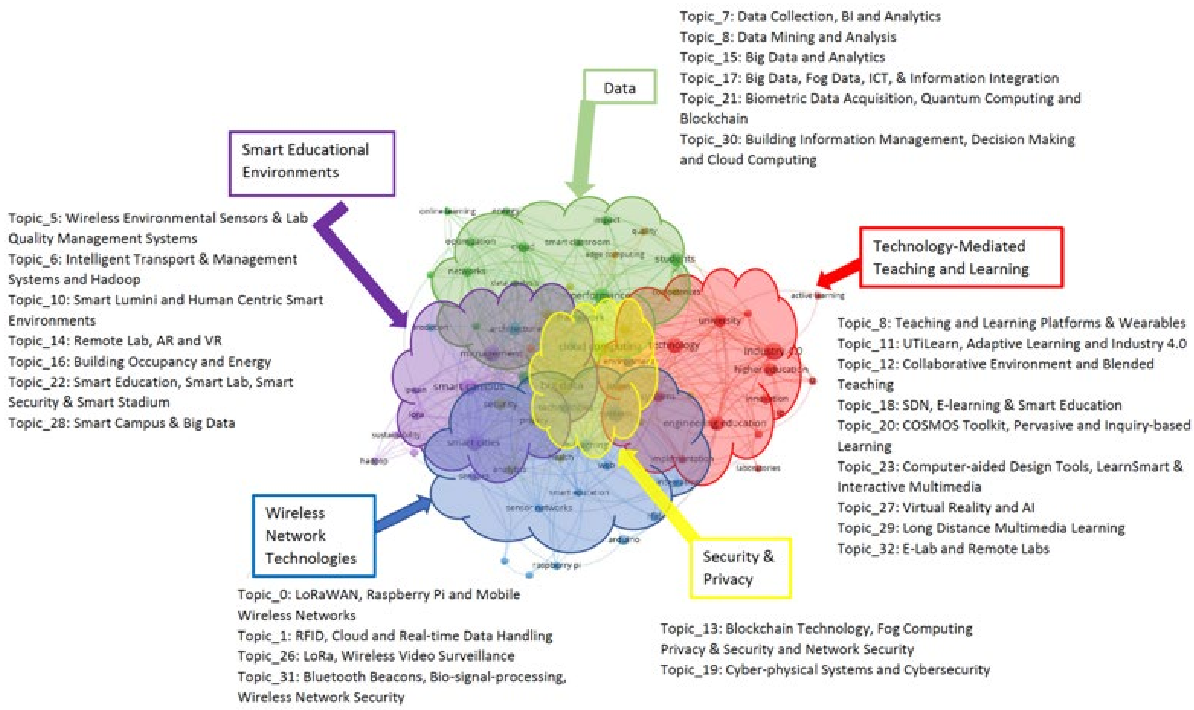

Figure 7. Keyword Occurrence Network

4.2.1 Keyword Cluster 1: Wireless Network Technologies. In this cluster, sensor networks, Arduino, RFID, and Raspberry Pi were typical keywords. Wireless Sensor Network (WSN) is considered a crucial element of the IoT model, and WSNs allow IoT scalability and provide support for its integration with the architecture of the Internet (Del-Valle-Soto et al., 2019). Thus, sensor network technologies are directly related to smart cities and smart classroom implementation. Zhou et al. (2020) proposed the optimized tracking of wireless video surveillance systems for the smart campus. This cluster overlaps with the Data and Smart Educational Environments clusters.

4.2.2 Keyword Cluster 2: Data. Studies in this cluster mainly focused on data handling in IoT environments. Data analysis, cloud, networks, students, performance, and smart classroom are prominent keywords. IoT systems generate various data, and a proper method of data handling is needed for efficient decision-making. Moreno et al. (2017) proposed a framework to share and handle huge volumes of heterogeneous data generated in IoT environments. Verma et al. (2017) proposed an automated student performance evaluation system based on the data collected in learning environments. Lee et al. (2019) suggested a performance evaluation matrix to construct a model for evaluation and analysis to improve online systems with the advancement of IoT. This cluster overlaps with Smart Educational Environments, Security and Privacy, and Wireless Network Technologies clusters.

4.2.3 Keyword Cluster 3: Security and Privacy. Keywords in this cluster have mainly focused on the areas of security and privacy. In this cluster, we see keywords such as big data, security, privacy, cloud computing, analytics, and health. Adams (2017) focused on big data and the IoT using examples of data privacy threats to describe the impact of personal data loss. In addition, Humayun (2020) focused on the convergence of the Internet of Things, cloud computing, and big data, which provides both opportunities and challenges in various domains including education. Weinberg et al. (2015) highlighted the opportunities and challenges of IoT and focused on the prominent issue of privacy and secrecy. This cluster overlaps with the Data and Wireless Network Technologies clusters.

4.2.4 Keyword Cluster 4: Technology-Mediated Teaching and Learning. Many studies in this cluster are mainly devoted to IoT technologies to facilitate teaching and learning. The major keywords are technology, industry 4.0, innovation, higher education, and active learning. For example, Khan (2018) defined the Industrial Internet of Things (IIoT) and focused on the need for higher education transformation in the era of the fourth industrial revolution. In addition, Chong et al. (2018) focused on the benefits of integrating 3D printing and Industry 4.0 into engineering programs, finding that these technologies are beneficial in creating a student-based learning environment. Yang (2012) studied and proposed the design of a teaching platform architecture based on IoT. This cluster overlaps with all the other clusters.

4.2.5 Keyword Cluster 5: Smart Educational Environments. Studies in this category are focused on smart educational environments. Some dominant keywords are smart campus, smart cities, sensors, and sustainability. Villegas-CH et al. (2019b) implemented a sustainable smart campus using big data and Hadoop architectures to work with large volumes of data. Hernández-de-Menéndez et al. (2020) present a comprehensive study of various tools available for transforming education along with their benefits and suggestions for future implementations. The topics and keywords in this cluster overlap with those of all the other clusters.

Based on our exploratory analysis, we concluded that the technical aspects of IoT have been considered by the researchers; for the most part, however, they fail to embrace the socio-technical systems (STS) thinking (Davis et al., 2014) that considers "two jointly independent, but correlative interacting systems" – the technical (processes, tasks, and technology) and the social (attributes of people), and deals with both systems in an integrated way (Bostrom & Heinen, 1977).

In the current literature, the social challenges have received less focus compared to the technical challenges. For instance, technical aspects such as Infrastructure, Interoperability of data, Security and Privacy of data, data analysis algorithms, Security of services and infrastructure (Gilman et al., 2020), personalized learning solutions (Iqbal et al., 2020) performance in dynamic environments (Kulkarni et al., 2020) have been widely addressed. However, social concerns such as the cost of implementation (Hernández-de-Menéndez et al., 2020), ethical issues (Gilman et al., 2020), reluctance to change (Romero-Rodríguez et al., 2020), energy consumption (Hossain et al., 2020) appear to be underexplored.

Overall, all these clusters favor technical issues more than social issues. Furthermore, within the technical domain of IoT in education, researchers seem to have given more importance to smart educational environments and data as illustrated in Figure 7. To obtain deeper insights into these clusters, we analyzed them with a view of potential opportunities, challenges, and research gaps in the study of the IoT in education from social and technical perspectives as reflected by the researchers in the current literature. Table 3 summarizes the challenges and limitations faced during the implementation of campus projects and potential future work areas as reflected in the current literature.

Cluster	Perspectives	Challenges	Potential Research Questions
Wireless Network Technology	Technical	Interoperability of heterogeneous devices	How could one ensure coordinated communication among different devices, systems, solutions, and products of a smart educational environment?
		Scalability	What are the techniques to identify and resolve network scalability issues?
		Performance in a dynamic environment	How could one design networks that adjust their parameters to provide maximum performance in a dynamic environment?
		Complexity of networks	What are the techniques to handle network complexity issues as the number of nodes in the network increases?
	Social	Energy consumption	What are the technologies available to monitor and overcome the challenges of energy consumption issues in Wireless Networks?
Data	Technical	Interoperability of data	What are the ways to identify and handle data coming from various sources?
		Delay issues	How do institutions identify, and handle delay issues caused during data aggregation?
		Data analysis algorithms	What are the appropriate methods to analyze the data from smart environments?
	Social	Ethical issues	What ethical considerations need to be addressed in terms of data collection?
Security & Privacy	Technical	Security of services and infrastructure	What are the authentication measures required to ensure the proper safety of services and infrastructure?
		Security and privacy of data	What technologies can be used to ensure proper privacy and security of user data to avoid exposure of sensitive information?
	Social	Ethical usage of data	What are the precautionary measures required to avoid misuse of information collected in the shared smart spaces?
Technology-mediated Teaching & Learning	Technical	Technical expertise	What kind of technical expertise is required by teachers and students to use the technology successfully?
		Personalized learning solutions	What are the methods to evaluate a person's learning patterns/ behavior/ attributes/ performance and design a system accordingly?
		Cyber ethics	What are some of the efficient ways to educate students on cyber ethical behavior and create awareness?
		Student's perception	How could one conduct a perception evaluation using learning attributes and performance?
	Social	Pedagogical expertise	What kind of pedagogical skills is required by the teachers to set up tasks for the students in the smart learning environment?
		Reluctance to change	What is the level of willingness of teachers and students in accepting and adapting to the usage of technology in teaching and learning?

		Resources availability	How could one ensure that the required resources are accessible to the students?
		Economic constraints	What are the measures to address the financial constraints of the students that block them from accessing the technologies required for learning in the smart environment?
Smart Educational Environments	Technical	Infrastructure	How could the installation, support, and maintenance of technical components of a smart educational environment be handled?
		Performance of the system	How do institutions ensure the efficient performance of all the interconnected systems that form Smart educational environments?
	Social	Management and support	Who is responsible for managing the system and providing the required support?
		Cost of implementation	What are the ways to address the cost issues involved in the implementation of smart educational environments?
		Legal regulations	What are the legal regulations that need to be considered while implementing smart educational environments?

Table 3. Challenges and Opportunities on IoT in Education for Further Research

4.3 Contributions in Various Research Areas

In this section, we analyze the contributions and implications of studies related to IoT in various research areas that were obtained from the WoS database. We performed this analysis, using the statistics in Figure 5, to select the top 4 categories: Computer Science, Engineering, Education & Educational Research, and Telecommunications. Table 4 presents the summary of the dominant topics discussed under each research category.

Research Areas	Dominant Areas
Computer Science	Cloud Computing, Big Data, Smart Cities & Campus, VR, Machine Learning, AR
Engineering	Industry 4.0, Smart Cities, Engineering Education, Cloud Computing, Smart Campus, Big Data, LPWAN, Arduino, LoRa, Energy Efficiency
Education & Educational Research	Industry 4.0, Big Data, Natural User Interfaces, e-Learning, Smart Cities, Smart Education, Active Learning, Smart Learning Environment
Telecommunications	Cloud Computing, Smart Campus, Big Data, Smart Cities, LoRa, Privacy, Wireless Sensor Networks, Real-time Systems, VR

Table 4. Dominant Keywords Under Research Areas

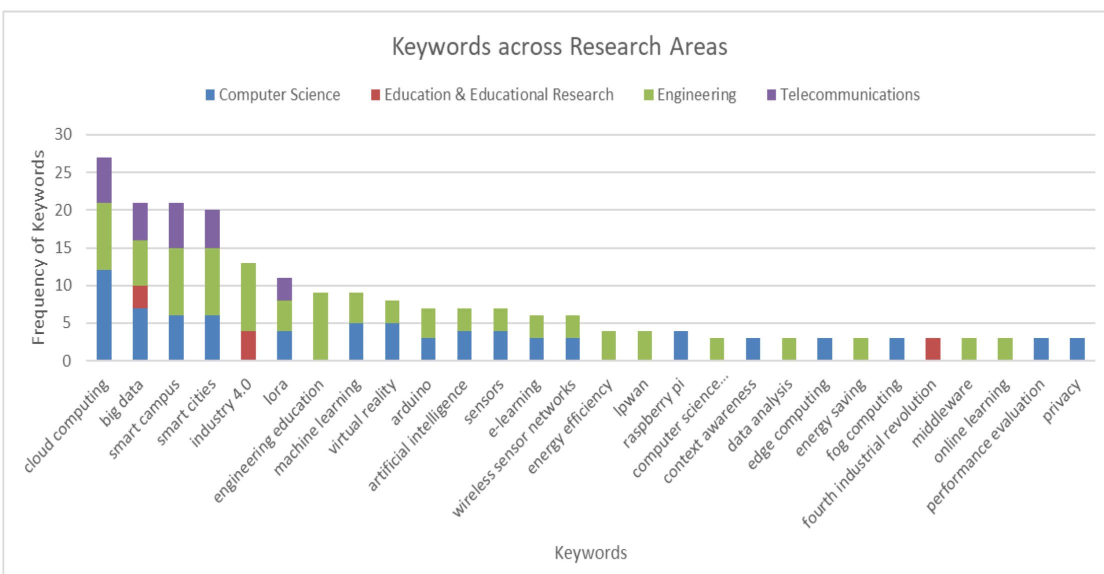

Figure 8. Keywords Across Research Areas

Figure 8 shows the occurrence of dominant areas across multiple disciplines. It is evident that there are similarities in research trends in these different areas. For example, big data is an area of interest in computer science, engineering, education & educational research, and telecommunications. In the field of computer science and engineering, areas of machine learning, VR, AI, and sensors have appeared. The study of research trends in various areas helps in the understanding of technology and idea dissemination among these areas.

IoT is a complex implementation that requires expertise from various disciplines and domains to facilitate the design, development, and implementation. In this direction, future researchers can conduct studies to understand the overlap, identify the gaps and explore ways to borrow more information from multiple fields to provide innovative solutions.

5. CONTRIBUTION AND IMPLICATIONS

In this study, we employ text-analytic and bibliometric analysis to provide a detailed view of research trends in IoT in education. Specifically, we show the areas that have been explored thus far, summarize potential research gaps reflected in the current literature, and some challenges. Thus, we provide a preliminary road map for future research and contribution to IoT in education. With the help of an extensive exploratory data analysis, followed by topic modeling and keyword co-occurrence analysis, this study yields some detailed insights. We identify and highlight existing solutions for integrating technology in the classroom to enhance the delivery of education. The education domain is no stranger to the use of technology to provide solutions in the classroom, and this leads us to highlight some solutions that have already been implemented and tested. This serves as a guide to help educators and institutions to analyze and select an existing solution that fits their needs.

In addition, our study generates several insights for stakeholders in the educational domain. Our analysis suggests that most of the studies on the IoT in education are focused on the technical and functional viewpoint, with an emphasis on aspects of building and implementing components of the system. Since the IoT application in education has been driven by the interaction between people and technology, it has become necessary to consider the socio-technical perspective (the blending of the technical and social dimensions) when building these systems. Without considering the social dimension, it is difficult to design a system that enhances the user's quality of life. Our analysis shows that socio-technical aspects, e.g., stakeholder perception, adaptability, training, motivation, and other psychological factors, are not as common in the literature as the technical aspects. Employing an approach that considers the integration of both aspects will result in more efficient and realistic applications of the IoT in education.

Our study reveals key thematic areas that dominate the research on the IoT in the education domain. It is evident that educational institutions will be able to benefit from the IoT only if they provide an efficient, reliable, and scalable infrastructure that is available to all stakeholders without interruption. The implementation involves integrating technology to facilitate teaching and learning and providing smart solutions in educational institutions serving students of various age groups and academic backgrounds. This is because students, teachers, and stakeholders in various parts of the system have different levels of technical abilities and knowledge. Thus, it is crucial to design robust, secure, and easy-to-use systems that can benefit even non-technical stakeholders without much support.

5.1 Strategies for IoT Education

Table 5 summarizes some of the campus projects in the current literature. We highlight the main technologies used in the implementation of these campus projects in the "Knowledge/Skills Needed" section of this table. We used this information to create a list of courses the IS educators should consider including in their curriculum. The suggested IS courses are the actual courses taught at many universities in the field of Information Systems such as the University of California, Berkeley, Carnegie Mellon University, New York University, Georgia Institute of Technology, the University of Texas at Austin, and so on. We chose these universities as a reference point to make suggestions based on their course descriptions. Although not exhaustive, the "Possible IS Course placement" list is intended to provide IS educators with a guide to existing courses that can be included. Due to the depth of the concepts and practical knowledge required, it will be beneficial to the students' learning if these are implemented as dedicated courses. Also, since the clusters are different parts of an IoT system and are overlapped, it makes the curriculum stronger if it includes several related courses, depending on the level of training required and the area being focused on.

Cluster	Campus/University Projects	Knowledge/Skills Needed	Possible IS Course Placement
Wireless Network Technology	LoRaWAN Fog Computing Based Architecture for IoT Enabled Smart Campus Applications	LoRaWAN, LPWAN, Fog Computing, Sensors	Networking Architecture & Protocols
	Real-time Bio-signal-processing of Students Based on An Intelligent Algorithm for the Internet of Things to Assess Engagement Levels in Classroom	Artificial Intelligence	AI, Society, and Humanity
	Emotionally Aware Virtual Assistants	Deep Learning, Neural Networks	Natural Language Processing with Deep Learning
	Campus Edge Computing Network Based on IoT Street Lighting Nodes	Edge Computing, Machine Learning, Resource Management	Machine Learning and Data Analytics for Edge Artificial Intelligence
Data	Real-time Data Collection Building Information Modeling (BIM)	Data Management and Monitoring, Big Data, Web Services, CAD	Big Data Analytics and Visualization

	Applicability of Big Data Techniques to Smart Cities Deployments	Big Data, Data Mining	Big Data and Development
	A Hybrid Infrastructure of Enterprise Architecture and Business Intelligence & Analytics for Knowledge Management in Education	Big Data, Educational Data Mining, Data Warehousing, Business Intelligence and Analytics, ETL, Enterprise Architecture	Applied Data Analytics and Modeling for Enterprise Systems
	Data Mining Analysis of Overall Team Information Based on the Internet of Things	Data Mining, SVM	Data Mining
Security & Privacy	Secure System for the Internet of Schools Things (S-IoST)	Cybersecurity, RFID, GSM, GPS	Information and Privacy in Society
	Fog Computing for Privacy and Security	Fog Computing	Introduction to Information Security
	Blockchain	Blockchain Technology	Blockchain Uses and Applications
	RFID for Student Identification and Tracking	RFID Technology	Introduction to RFID Systems
Technology-mediated Teaching & Learning	Cloud & Wireless Networking-based Educational Platform	Software-defined Radio, Sensors, Web Front-End Interface and Web Back-End Server, IoT Management Framework	Front-End Web Architecture
	VR Solutions	Virtual Reality, Cloud Computing, Computational Modeling, Solid Modeling	Virtual Environments
	LearnSmart: A framework for Integrating the Internet of Things Functionalities in Learning Management Systems	Laboratory Controller, Robotic Arm, Sensors for Remote Lab and Python, PHP, HTML, SQL, Raspberry Pi, RNN	Technologies for Creativity and Learning
	Computer Assisted E-Laboratory using LabVIEW and Internet-of-Things Platform as Teaching Aids in the Industrial Instrumentation Course	Proportional, Integral, and Derivative (PID) Control System, Mobile App, Arduino, LabVIEW	Mobile Application Development
Smart Educational Environments	Energy Management System	Raspberry Pi, LoRa, Sensors	Managing Energy: Risk, Investment, Technology
	Environmental Quality Management for Indoor Laboratory Conditions	Web Services, SQL, Mobile App	Mobile Web Design and Development
	Car Parking System for Smart Campus	Mobile App, Web Services, and Cloud	Mobile Application Design and Development
	Smart Stadium	MATLAB, Machine Learning	Applied Machine Learning

Table 5. Strategies for IoT in Education

6. CONCLUSIONS

In the modern technology era, we are witnessing increasing use of IoT technology, connected devices, smart devices, and sensors in education, which is revolutionizing learning and teaching experiences. Our paper is focused on prior academic research related to IoT in the education domain. With the development and evolution of modern technologies, educational institutions need to constantly assess current systems to address the opportunities and challenges for the future of smart campuses. Technology dependency has been increasing rapidly in the education sector over the past few years, particularly during the COVID-19 pandemic when most universities employed IoT technologies to facilitate e-Learning for students who were previously taught in a classroom setting. This shift to technology dependency has provided researchers with an opportunity to analyze existing issues, address new challenges, and evaluate potential gaps in academic research to solve these real-world problems. Thus, we must understand what has been explored so that it can lead to providing enhanced teaching and learning environments for all stakeholders in education.

In this paper, our preliminary analysis shows that researchers focused mainly on the technical aspects of the system, leaving many social aspects unexplored. Using topic modeling and keyword co-occurrence analysis, we identified five major research areas, that is, Wireless Network Technologies, Security and Privacy, Data, Smart Education Environments, and Technology-mediated Teaching and Learning. Further, we identified technical, social, and organizational challenges that are observable in our data. Thus, our paper explains key research themes and provides a roadmap for future research on the IoT in education.

7. LIMITATIONS AND FUTURE RESEARCH

This study is constrained by some limitations. First, we conducted it mainly depending on academic research papers fetched from a bibliographic library database – WoS. The data obtained from such a database are susceptible to a considerable amount of noise, and a manual elimination process might be needed to remove it. Second, our study provides insights into research areas explored by scholars in the field; however, it does not provide a comparison with the state of the art in industry. Finally, we focused on the key thematic areas of the IoT in education. A detailed text analysis, including our topic modeling approach, could reveal more specific areas of research. Despite these limitations, we believe our study is a step toward understanding research regarding the IoT in education, which, in turn, can serve as a guide to future researchers with broader opportunities to contribute toward better technology in education.

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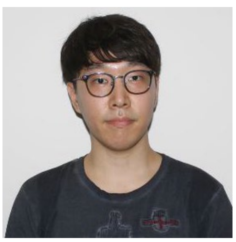

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