Investigating the impact of IoT-Based smart laboratories on students’ academic performance in higher education

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Abstract
The enormous developments in technology have transformed the way we interact with the world around us. Among the extensive yet advanced technological interventions, one of the sophisticated expansions is the appearance of the Internet of Things, a tool for developing connections of physical objects to the virtual world using small-sized sensors and certain internet protocols to lessen human interventions. The domain of education has also adopted these technological services to move from traditional methods to sophisticated and advanced teaching and learning approaches to cope with learning needs and raise quality. This paper intends to conceptualize the impact of integrating IoT in higher education to increase students’ academic performance in the engineering domain through the integration of smart laboratories. Several international studies were selected and thoroughly reviewed using the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analysis to build sophisticated insights regarding the topic in terms of its conceptual as well as practical foundations. The key insights gathered through reviewed studies indicate that the Internet of things-based laboratories have significant advantages in uplifting students’ academic performance through interaction, motivation, creativity, and practical learning. The integration of the Internet of things in higher educational institutes improves students’ academic performance because it allows them to engage in authentic tasks and experience practical and active learning.

Keywords Internet of things · Higher education · IoT-Based smart laboratories · Students’ academic performance

1 Introduction

The massive developments and the extended role of technology placed a notable influence in almost every sphere of life, especially during the Coronavirus (COVID-19) pandemic. Likewise, the domain of education has also confirmed its growing tendency to adopt the changes underlying technological advancements to strengthen the teaching and learning process, as the traditional and outdated methods are no more attractive to learners of the current era [32].

The evidence of the origin of the term “Internet of things” is visibly found back in the late ‘90 s from the work of one of the British technology pioneers Keven Asthon, who described it as the system which employs the use of sensors for connecting the physical world objects to the Internet [41]. He nominated this term to expound on the process of using Radio Frequency Identification (RFID) labels for auto-tracking goods without considerable human interference. Recently, the Internet of things has significantly expanded to various objects, devices, and everyday items. It has received
wider recognition in various disciplines, including computer science, engineering, business, and education [19].

The role of the Internet of Things (IoT) in education is not only limited to the teaching and learning process but also serves the educational institutes to manage and track their key resources effectively (Mrabet and Moussa, 2017). It enhances students’ access to information within and outside of the classroom and provides an interactive and active learning environment [33]. It enables students to get a variety of opportunities to learn in a collaborative environment, doing hands-on practices and demonstrating notable academic improvement in terms of conceptual understanding as well as technical aspects of learning [44]. In addition to that the IoT-based smart classrooms and laboratories in higher education brought a paradigm shift in the teaching and learning process, especially in engineering and software engineering domains. The inclination toward the use of IoT in education is so obvious that IoT-based practical courses now tend to be introduced in engineering education as per the instructions of the statutory technical training bodies.

Excitingly, it is worth arguing that the existing education system has to make necessary amendments to equip itself with the modern tools and technology to implement a modern curriculum for digitalize students learning [4]. This requires the use of modern resources such as digital smart laboratories and smart devices to meet the diverse learning needs of the students of the twenty-first century who can offer their services better fit to the current industrial and technological era (Mrabet and Moussa, [11]). In this regard, students need to be given hands-on exposure to handling smart devices to develop necessary understanding and skills through enhanced communication, connectivity, and an active learning approach.

The evidence from the research of IoT-based learning at higher education levels highlights that adaptation to IoT-based technology-supported smart campuses tend to be increased due to the positive impact of engaging students in IoT-based learning on their academic performance. For example, Montori et al. [26] in their study regarding the impact of introducing IoT-based courses in the engineering domain, quoted the statistical data of the technical reports regarding the adaptation to IoT devices. Reports indicated that around 31 billion IoT-based networking devices are currently working at different levels, which will reach around 75 billion in the upcoming five years. The rise in the demand for IoT-based technology opens up the way of opportunities for engineering and software engineering domain students to contribute to the development of IoT-based technology to strengthen the country’s economy and better respond to the demands of industrial revolution 4.0.

The remainder of the paper is structured as follows. The authors explained the review objectives and research questions step-by-step in Sect. 2. Section 3 discusses the architecture of IoT. Section 4 explores the IoT communication model. Section 5 is based on the methodology while Sect. 6 focuses on the overview of different studies. Section 7 presents the results from the detailed review and data analysis process supported by the literature. Section 8 outlines the discussion part and finally, Sect. 9 offers conclusions and future directions.

2 Review objectives and research questions

This study attempts to develop an understanding of IoT application in education based on the empirical studies and postulates the uses of IoT, particularly in higher education. The study aims to propose a synthesis of the existing literature in improving students’ academic performance by interactive learning in IoT-based smart laboratories. The study also takes account of a variety of existing communication models of IoT in general and its framework particular to the education domain. It also intends to direct the education community to understand the critical and practical foundations and implications of the enhanced role of IoT in the education domain by building comprehensive insights.

The review attempts to answer the following overarching and subsidiary research questions to achieve the study’s objectives:

RQ. 1. What impact do IoT-based Smart laboratories have on students’ academic performance at higher education?

RQ. 1.1. What is the current state of design and implementation of IoT-based smart laboratories in higher education?

RQ. 1.2. How is the domain of education being privileged through the integration of IoT?

RQ. 1.3. How is students’ academic performance influenced by setting up IoT-based smart laboratories at higher education institutes?

RQ. 1.4. What are the challenges underlying the integration of IoT in education?

3 Internet of things architecture

Among the emerging technological trends recently, IoT is expanding its roots in the field of education with a significant impact. IoT is considered a system of smart devices with interconnected sensors through the Internet [18]. The International Telecommunications Union (ITU) defines interconnectivity as the tendency to devise links between the physical and virtual world by effectively utilizing information and communication technologies [17]. The Internet Architecture Board (IAB) postulated "The Internet of Things" (IoT) as a development that allows a large number of embedded
devices, referred to as smart objects, to be integrated into each other by utilizing necessary Internet protocols for communication. Smart objects have the capability of reducing human efforts to the extent that they do not require to be directly handled by humans, rather, they are integrated into buildings or vehicles [32]. To a greater extent, the proposed definitions have comprehensively illustrated the concept of IoT in its structural perspective that there need to be some smart objects embedded with sensors and stable internet connectivity to link the devices to each other. However, they seem lacking in highlighting the functional perspective of IoT and how the connection of these large numbers of devices to the Internet is managed. The instances of the functional perspective of IoT are found in the work of Al-Fuqaha et al. [1], which states IoT as a system of different objects, having distinct addressing schemes for their unique identification, connected by wired or wireless means.

According to Kumar and Patel [17], the IoT network architecture consists of three layer. The base layer is known as the sensing or the recognizing layer. Through this layer, the unique identification of the IoT device is made, and it allows the IoT device to sense the data from the surroundings. This layer gathers the data using small, inexpensive, and readily available sensors because they are commonly used to track humidity, pressure, vibrations, etc. Sensors are entrenched in various objects such as smartphones, computational devices, and wearables. The second layer in IoT network architecture is the network layer, as shown in Fig. 1.

The network layer is responsible for handling the data from an operational perspective. The network layer may support a variety of networks such as Wireless LAN, MAN, wide area network, personal area network, or Internet. This layer also serves to accumulate the data at the gateway, analyze the data and restrain irrelevant data, and send it to the next layer for interpretation. The top layer of IoT architecture is the Application layer which provides the interpretations of the data to users [34].

### 4 IoT communication model

IoT is the result of advancements in sensor-based technology and Information Technology and Communication (ITandC), operated through a variety of models [33]. For example, many of the IoT objects, connected IP-based networks and cloud computing, etc., seemed to appear even before the emergence of the concept of IoT itself. Still, these devices are not globally acknowledged [29]. However, the emergence of IoT in 1999 in the form of integrated smarter physical devices and ubiquitous interconnectivity opened up a new era of technology. The Internet Architecture Board proposed four major communication models of IoT.

#### 4.1 Device-to-device communication model

In this model, two or more devices are connected directly and communicate with or without an intermediary application server, as shown in Fig. 2. The devices tend to connect over several types of networks, such as IP networks or Internet services, using special examples of this model [41]. However, these device-to-device connections have certain
limitations, as the connected devices should be at a certain predetermined range.

4.2 Device-to-cloud communication model

Ray [37] defines cloud services that allowing access to various applications and resources without having infrastructural and hardware objects in place. Rather, these services are approached by the user by using the Internet, for example, email services or working collaboratively in a file from different places. In this model, devices are directly connected to an internet cloud service, as shown in Fig. 3. However, disconnectivity from internet cloud service providers cannot be fixed by users until the cloud network administrator may be notified and attempts to fix it.

4.3 Device-to-gateway communication model

The model shown in Fig. 4 is a device-to-application-layer gateway (ALG), which refers to a network system where devices are neither directly connected nor the internet cloud service. It is an intermediate software application between cloud computing services and an Internet device, which the user operates through a gateway [34]. A gateway is a physical device or a software program that serves to process or communicate the data between IoT devices and internet cloud service. It acts as a network router that connects the IoT device of the user to the cloud and the user may access the device through smartphone applications [1]. This type of connectivity does not allow the user to access internet cloud services but it provides advanced functions such as data and protocol translation and improved security systems.

4.4 Back-end-data-sharing communication model

This model (Fig. 5) permits users to access, share and analyze the collection of data from multiple smart devices. Users can provide access to uploaded data to third parties using cloud services [17]. This model is usually used in organizations where employees' smart devices such as devices.

Fig. 3 Device-to-Cloud Communication Model. Note. Adapted from “An Overview of Security Issues Relating to the Internet of Things” by G.R. Akeredolu, A.A. Elusoji, J.N. Odii, A.W. Akanji and A.E. Aiyegbusi, 2016, Computing, Information Systems, Development Informatics and Allied Research Journal, 7(3), 63–70. (https://www.researchgate.net/figure/Device-to-cloud-communication-model-diagram_fig2_334603508)

Fig. 4 Device-to-Gateway Communication Model. Note. Adapted from “An Overview of Security Issues Relating to the Internet of Things” by G.R. Akeredolu, A.A. Elusoji, J.N. Odii, A.W. Akanji and A.E. Aiyegbusi, 2016, Computing, Information Systems, Development Informatics and Allied Research Journal, 7(3), 63–70. (https://www.researchgate.net/figure/Device-to-gateway-communication-model-diagram_fig3_334603508)
laptops are connected to the central company’s server and the higher authorities may access all the devices working within the office building or connected through the cloud [37]. The model is thought to be the extended version of the device-to-cloud model, where IoT devices tend to share data with only a single application service provider. Still, it enables multiple devices to get access to data.

4.5 Models and frameworks of integrating IoT in higher education

Several models and frameworks are found in the existing literature that provides infrastructural, pedagogical, and interactional aspects of the IoT-based smart learning environment in higher education.

4.5.1 Pedagogical triangle for IoT-based learning approach

This model is proposed by Mrabet and Moussa [12] for elementary and secondary levels of education. This model has placed considerable emphasis on the IoT-based learning approach represented through a pedagogical triangle. The proposed pedagogical triangle is encircled by IoT-based technology (as shown in Fig. 6).

In this model, the classical pedagogical triangle structure is adopted but with modifying the construct of devices with the smart devices for communication and collaboration within the educational environment. This model postulates the teachers’ identity and role in two dimensions. The first role of the teacher in the smart learning environment is to serve as a mediator in the learning process. It confirms a strong pedagogical relationship with students to assist in the knowledge acquisition process. It regulates and constructs interactive tasks for students to develop interest and motivation among students. The other role of the teacher is expressed as the medialized, which enables him to help students transform the acquired knowledge into a sophisticated comprehension of the learned content.

4.5.2 A model of IoT in academia

Banica et al. [4] proposed a network architectural model for academia through which smart universities can be operated for maximizing students learning outcomes. This model entails that cloud computing services have to be utilized to
deliver real time and limited area services for IoT integration to solve problems of transforming the traditional to smart universities. An IoT architecture is proposed for smart universities with three layers (as shown in Fig. 7).

In this architecture, IoT devices are represented as a wireless sensor network which is the first layer of the IoT architecture. The second layer is Cloud Computing, which provides various services such as access to software and security of the data. The third layer of big data analytics uses databases to generate an interpretation of the data by disclosing the hidden patterns in the data that are then communicated to IoT devices.

5 Methodology

5.1 Research synthesis process and literature search

The current literature review offers insights by summarizing the recent studies and combining the summaries of the articles comprehensively. It revolves around the themes or areas frequently found in the current body of existing literature. This literature review involves the process of firstly identifying the key constructs that are essential to understand the topic of review, finding the existing key studies that are relevant to the topic, reviewing and analyzing the data that is proposed in those studies, and at last but not the least the interpretation of the results and future pathways for the further exploration of the topic. The inspiration for the study is the emerging trends of technology-equipped education in response to the urgencies of industrial revolution 4.0.

The literature search has been carried out from five databases, including Springer, IEEE Xplore, ACM Digital Libraries, Taylor and Francis and Wiley Online Library, because they offer easy access to the full-text journals and the details of the most important conferences from various domains. Two search strings have been used to find the relevant articles from each database. The first string is set up to gather data on structural aspects of IoT, including the keywords “internet of things” OR “IoT”, “smart laboratories in higher education” OR “IoT labs”. The second string is made up of functional aspects of IoT, including the keywords “IoT in education” OR “IoT in higher education” OR “Impact of IoT in students learning” “IoT labs and students’ academic performance”. The search was confined to predefined criteria of publication year from 2015 to the present using advanced search and applying filters as depicted in Table 1. In total, 932 articles were initially identified during the search process.

5.2 Selection process and criteria for inclusion

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [31] are followed for determining and reporting the systematic literature review process. Before the screening, 501 articles were removed by using automation tools subsequent to duplication and non-relevance and exclusion of either search string. The initial screening the process included (a) the reading of the title, abstract, and keywords and the elimination of the articles that were not relevant to research objectives, (b) searching for the full text available and, (c) the nature and relevance of the study to our research questions.

The screening process resulted in 60 further evaluated articles against the inclusion criteria, including (1) The explicit focus on the use of IoT in education, (2) The year of publication from 2015 to 2022, (3) The relevance of...
study objectives with our research questions, and (4) The study findings adequately address our research questions. The evaluation process resulted in the recruitment of 32 articles for review based upon their pursuance of inclusion criteria. Figure 8 shows the process of systematic inclusion of studies.

6 Overview of the studies

This review encompasses the recruitment of Cross-cultural studies in order to gather comprehensive insights for answering the research questions sophistically. The studies were taken from different countries including the USA (03), India (03), Italy (03), Pakistan (03), Greece (02), Mexico (02), Bangladesh (01), China (01), Colombia (01), Dutch (01), England (01), Finland (01), Germany (01), Mauritius (01), the Netherlands (01), the UK (01), Hong Kong (01), Lebanon (01), Brazil (01), Canada (01), Australia (01) and Turkey (01), as shown in Fig. 9.

The studies were conducted by adopting different methodologies, including Qualitative, Quantitative, Systematic/Analytical Review, and Mixed Methods. The reviewed studies were accessed from five databases, including SpringerLink (11), IEEE Xplore (08), ACM Digital Libraries (05), Taylor and Francis (05) and Wiley Online Library (03). All 32 reviewed studies have their publication dates between the years 2015 to 2022 (shown in Fig. 10).

7 Results

The following insights emerge from the detailed review and data analysis process supported by the literature.

| Data source                  | Search settings                              | Applied filters                                                                 |
|------------------------------|----------------------------------------------|---------------------------------------------------------------------------------|
| SpringerLink                 | Sort by relevance                            | Sort by date published from start year “2015” to end the year “2022”, Content type to “articles”, Discipline to “engineering” and “Computer science” and Language to “English” |
| IEEE Xplore                  | Sort by relevance and with advanced search   | Publication year from “2015” to “2022” and by content type to “conferences” and “Early access Articles” |
| ACM Digital Library          | Sort by relevance                            | Search items from the ACM Full-text collection, Search within “anywhere”, custom range of publication date from the Month of “January” and Year “2015” to Month “January” and Year “2022” |
| Taylor and Francis           | By default search                            | Without filters, in the search bar by entering all keywords, Sort by “Articles” |
| Wiley Online Library         | Sort by relevance and with advanced search   | Sort by context to “anywhere” and custom range of publication date from the Month of “January” and Year “2015” to Month “January” and Year “2022” |

Fig. 8 Flow diagram for a process of Systematic Inclusion of Reviewed Studies

7.1 Design and implementation of IoT-based smart laboratories to approach educational revolution

The results of the review indicate that several studies aimed to investigate the structural and functional aspects of IoT-based Smart laboratories. It is proposed by Knight et al. [16] that smart laboratories are quite similar to IT laboratories but they integrate the latest technologies that are grounded in the Internet of Things (IoT) and mobile applications.
Shweta et al., [42], while discussing the importance of these laboratories, stated that the demand for IoT laboratories in higher education is significantly raised during COVID-19. Similarly, Khriji et al. [14] in their study of smart laboratory design and implementation expressed the idea that smart laboratories are intended to develop within university campuses so that hands-on experience with IoT objects would be provided to students. Unsurprisingly, IoT-based courses are usually offered to engineering and software engineering students, but these laboratories’ significance is not just confined to them. However, Mohammed et al. [25] highlighted that due to disciplinary knowledge and engagement in IoT-based projects, students of the engineering domain tend to get maximum benefits out of existence and working in such laboratories.

Asghar et al. [3] discussed the IoT-based technologies application in the education domain and stated that smart laboratories usually have IoT technology, physical components, smart devices, software systems, and access to advanced cloud services. These laboratories support diversity in teaching and learning activities and advance pedagogy. They further build the idea that students get exposure to practical and active learning, simulations, and real-time interaction with sensors and other smart objects [30].

In their study of virtual academic communities, Rocha et al. [38] found that smart laboratories enable teachers to engage students in cognitive activities such as logic, pattern development, generalizing, and automation. IoT devices help students to go through multiple procedural steps for doing their project work, including (a) the process of analyzing multiple dimensions of the problem by breaking it down into inconvenient parts, (b) exploring similar patterns found in multiple pieces of the problem, (c) expanding focus toward substantial information of the problem and eliminating unnecessary details and (d) attempting to solve by using necessary rules [7].

7.2 Application of the internet of things in education

IoT can bring paradigm shifts in education in terms of pedagogical advancements, leadership roles, and innovation and creativity in learning. The majority of the reviewed studies have discussed the application of IoT in education. The studies extracted that the emergence of IoT in education brought major transformations in the teaching and learning process in developed countries. For instance, Prieto-Magnus et al. [35] highlighted that education tends to adopt virtual learning systems, online systems, and technology-supported smart classrooms. They argued that through these interventions, students with enhanced yet advanced opportunities to develop conceptual knowledge as well as technical skills relevant to the content. Similarly, Maenpaa et al. [21], based on their three years of action research on IoT projects at the university level, declare that
the introduction of robots and artificial intelligence has already replaced humans’ efforts.

Kim [15] explored the social aspect of IoT technology in education and highlighted that teachers with the help of IoT-supported devices engage students in personalized content, interactive presentation of ideas, and a variety of learning activities that address the learning styles and needs of students. Further, their study argued that IoT is responsible for providing the opportunity of self-regulated learning. Table 2 further elaborates on the application of IoT in education suggested in the reviewed studies.

From the human and campus resource management domain, Mylonas et al. [28] highlighted that through using IoT services, students’ attendance can be tracked. They further claimed that IoT-based services in smart campuses save energy costs and water. For instance, sensors-based objects for the hot water supply can control the hotness in the warm heaters and turn them off when the water gets heated to the desired degree, during off-campus hours and on weekends. Further, automatic lights recognize human existence in classrooms, corridors, etc., and automatically turn on and off. Campus security can also be enhanced by recognizing licensed cars or vehicles by their number plates, as Valks et al. [46] suggested in their study of developing smart campuses.

### 7.3 Advantages of integrating IoT in higher education

The literature on IoT in higher education revolves around the emergent consensus on maximizing the use of IoT in the mainstream teaching and learning process as it can provide a better educational experience [40]. Studies revealed that higher education campuses had sanctioned IoT in security cameras for observing students’ activities and, monitoring campus resources, regulating temperature and electricity [28].

Internet of Things in Higher education allows access to the vast body of knowledge in educational blogs, wikis, eBooks, tutorials, and recorded lectures [2]. Several online learning forums, including Google classroom, provide opportunities to maximize students learning [13]. Students can submit their assignments, and project reports using university Learning Management Systems (LMS). Several studies aimed to find out the effectiveness of IoT-integrated LMS in higher education for both physical and online learning. These studies found the positive impact of using LMS on students’ performance in terms of managing learning activities, easy access to study material and assignment submission [5]. For instance, Chytas et al. [9], in their study of the prediction of students’ academic performance in smart universities, tracked the students' LMS activities and their participation in online classes and used the data to identify the expected outcomes. Similarly, Mershad et al. [24] also acknowledged that IoT assists in managing LMS activities for restructuring the students’ experiences at smart campuses.

### 7.4 Impact of IoT-based smart laboratories on students’ academic performance

It is evident from the majority of studies reviewed that IoT-based smart laboratories tend to improve students’ academic performance by providing a smart learning environment and hands-on practical methods of interacting with smart devices. For instance, López Ríos et al., [20] in their case study investigating the effectiveness of virtual realities and IoT-based smart laboratories, found that students get...
hands-on experience with the technology by working in a smart environment relevant to the course content. It leads them toward extended conceptual understanding and the development of technical skills.

Literature suggests that technology-enhanced learning has the potential to bridge the attainment gaps among students in higher education by developing the element of motivation and interest [6, 23, 48]. Ramlowat and Pattanayak [36], while reviewing the use of internet IoT in education, found that students in higher education who are provided with smart learning environments at campuses tend to develop conceptual and critical thinking skills and their academic performance improves significantly. Majeed and Ali [22] proposed that real-time exposure to the technology and working on several assignments, projects, and tasks that require the handling of IoT objects results in better student performance and academic achievements. They argue that these laboratories enable students to interact with smart devices and applications in the presence of the teacher who works as a facilitator of learning.

Creativity and innovation are the ideas lie next to the goals of engaging students in an IoT-based smart learning environment, as Bruno and Canina [6] found while exploring creative thinking abilities in the current digital era. They found that students who are given exposure to IoT-based smart learning environments have greater creativity and reflective skills than those students who are engaged in traditional learning. According to Ceccarini et al. [8], students’ performance significantly increases when they are provided with the opportunity to develop their own IoT-based projects by utilizing smart laboratory resources.

The smart learning environment brought significant upgradation in pedagogies advancements and instructional practices (de Oliviera et al. [10]). Iqbal and Khalid (27]) also found that teachers’ role in smart laboratories is of high worth because the teacher decides the right technological implementation based on the student’s needs and capabilities. They developed an IoT-centric framework to increase students’ performance and maintain their motivation in smart learning laboratories. Similarly, Malhotra et al. [23] also suggested that the technology of connected devices, information access through the Internet, and communication among students and teachers provide extended means of developing knowledge and comprehension of complex problems and their solutions among students. Collaborative learning environments help students to learn from each other through active participation in learning activities.

7.5 Challenges in integrating IoT in higher education

Regardless of the considerable advantages of adopting IoT-based technology in education, some studies also suggest that this adaptation to IoT is considerably challenging and comes with several drawbacks. For instance, van Deursen et al. [47] draw attention to the data security and confidentiality concerns entailing IoT integration. The discussion on digital inequalities, automated decisions, and a large number of connected devices argues that it seems quite impossible for an entire IoT network to secure the data of many interconnected devices. Sultana and Tamanna [45] highlighted the challenges explored during their case study of IoT benefits and challenges in times of pandemics. They argued that privacy and security concerns arise because IoT devices collect and interpret students’ data and save it on an internet-based network, which may be daunting to the student’s privacy.

Unsurprisingly, Shah and Yaqoob [39] highlighted another challenge associated with IoT-based technology: stable connectivity. They elaborated that connectivity issues or poor signal strengths of students’ Wi-Fi or internet services may hinder the smooth process of connecting to the system of IoT architecture. Along with the lines of connectivity reliance, another possible challenge for the successful integration of IoT in a higher educational institute is the management attitude toward adapting innovative implementation [43]. The maintenance of IoT objects would also be challenging for the university management to the IoT adaptation.

8 Discussion

On the very naive lines of understanding developed through the existing body of literature on the very existence of IoT technology, it is essential to state that IoT, as the term itself suggests the use of the Internet to bring ease to the communication of humans to its outer world. Yet, the comprehensive discernments suggest that the significance of IoT goes beyond the disciplines. This study particularly aimed to investigate the role of IoT in higher education to support the ultimate goal of students learning. Currently, twenty-first-century students are supposed to build technical skills such as creativity, exploration, and critical thinking. Therefore, the domain of higher education is in the mode of adopting smart campuses equipped with smart and digital resources. The findings of the review confirm that the establishment of smart laboratories offers means to engage students in real-time hands-on learning to develop a conceptual understanding of the taught content, problem-solving skills and creativity, as suggested by Angeli et al. [2], Kim [15] and Maenpaa et al., [21]. It is a growing consensus acknowledging the strengths of IoT as a tool for bridging the gaps in teaching and the learning process.

Studies by Malhotra et al. [23], Sultana and Tamanna [45] and Zhuang et al. [48] claimed that the integration of IoT in higher education tends to improve students’ academic
performance significantly. This performance is measured through significant changes and improvements in their cognitive and intellectual capital, the renovation and perfection in their technical skills and the sophistication in their attitude toward learning new concepts and applying them to their context. IoT-based learning is not only confined to physical mode; instead, it also assists in online and virtual learning in times of pandemic (Iqbal and Khalid, 2019). It is depicted from the results that learning is now not only limited to the classrooms, but students and teachers can connect even outside the classrooms using IoT. Despite the notable advantages of smart laboratories in higher education, it is worth considering that the effectiveness of smart laboratories depends pretty much on teachers’ pedagogical competencies to engage students in authentic tasks during dedicated laboratory schedules, as suggested by Chytas et al. [9] and Mershad et al., [24]. The practical approach underlying the IoT-based smart laboratories significantly increases students’ interaction with the course contents. Teachers need to acknowledge IoT as a new actor in the teaching process that facilitates students to approach their coursework and final year projects. They need to create tasks that are not too complex and nor too easy but the complexity of tasks should be according to the competence levels of students. Evidence from the existing body of research reinforces that the education community shall demonstrate a flexible attitude to meet the needs of learners of the twenty-first century.

The application of smart IoT-equipped laboratories is not narrowed to higher education’s teaching and learning process. It offers extended ease for campus human and resource management [8, 13, 25]. Campus security, reduced energy consumption, temperature regulation, resource tracking and biometrics, face recognition, and vehicle tracking are advantages of IoT.

Undoubtedly, researchers have contributed to a considerable extent to the emerging notion of using IoT-based devices and IoT-embedded smart laboratories for improving students’ academic performance across multiple disciplines and contexts. However, the majority of studies are conducted in western contexts and developed countries. There is a need to gather context-based evidence on how IoT be integrated into the domains of education in developing countries with low-cost protocols and systems. In addition to this, specific considerations are neglected in several studies. For instance, the complexities of academic tasks in which students are engaged during laboratory hours and the nature of academic collaboration among students and teachers. Moreover, other factors, including university administration support, welcoming campus climate, and institutional practices to support IoT-based learning, are not yet empirically investigated.

The future work of adopting integrated IoT learning and smart laboratories framework for the noticeable improvement in students’ performance at higher education level needs to be directed toward investigating the pedagogies. Moreover, the challenges confronted by teachers and students also need to be explored so that effective teaching methodologies and authentic tasks should be designed to get maximum benefit. These are of high significance to applying smart laboratories to get maximum benefits from IoT-based smart laboratories on higher education campuses.

9 Conclusions and future work

The rapid and immense development in the domain of technology has significantly distorted the way we interact with the environment. IoT is one evidence of it, which is thought to be the tool to develop associations of physical objects to the virtual world using specific internet protocols. IoT utilizes a three-layer infrastructure to connect multiple smart objects of distinct and unique identification addresses with the help of wired or wireless means. To develop connections among these devices, several models allow direct communication among these devices or through midways or intermediary services such as software applications, cloud internet services or the gateway to establish connections among devices. The emergence of IoT in education advances the teaching and learning process so that students learning outcomes would be achieved to a better extent that is relevant to the current industrial needs. It is an attempt to move toward the educational revolution and prepare students who have a sophisticated understanding of the contents of their discipline and technical skills. IoT is essential for management, such as students’ attendance tracking systems, saving the campus energy, water, and electricity, and enriching campus security by adapting vehicle tracking and biometric features.

The development and of IoT-based smart laboratories in higher educational institutes tends to provide smart learning experiences to students, which increases the overall academic performance of students to a significant extent. These laboratories are equipped with physical IoT objects and software applications and tend to provide students with the opportunities to get engage in practical experience. A smart learning experience tends to increase students’ motivation, creativity, and interaction, leading to better academic performance. However, certain issues are needed to be considered such as the security and privacy of data as many devices are connected to IoT networks, the stability of the strong internet connection and the continuous professional development and certification of teachers. Future research should address the pedagogical instructions and students’ expectations and level of satisfaction regarding smart learning experiences. To ensure effective pedagogical interventions, teachers need to be engaged in continuous professional development and certifications related to IoT, which would be challenging for the university management.
Table 3 Details of selected studies (chronologically listed)

| Database                  | Year | Author(s)                              | Title                                                                 | Journal                                                                 |
|---------------------------|------|----------------------------------------|----------------------------------------------------------------------|--------------------------------------------------------------------------|
| IEEE Xplore               | 2015 | Asghar, M. H., Negi, A., and Mohammadzadeh, N | Principle application and vision in Internet of Things (IoT)         | International Conference on Computing, Communication and Automation, ICCCA 2015: 427–431 |
| Wiley Online Library      | 2016 | Kim, K. J                               | Interacting Socially with the Internet of Things (IoT): Effects of Source Attribution and Specialization in Human–IoT Interaction | Journal of Computer-Mediated Communication, 21(6): 420–435               |
| IEEE Xplore               | 2016 | Shah, S. H., and Yaqoob, I              | A survey: Internet of Things (IOT) technologies, applications and challenges | 2016 4th IEEE International Conference on Smart Energy Grid Engineering, SEGE 2016: i: 381–385 |
| SpringerLink              | 2016 | Rocha, A., Correia, A. M., Adeli, H., Reis, L. P., and Teixeira, M. M | IoT in Education: Integration of Objects with Virtual Academic Communities | Advances in Intelligent Systems and Computing, 445(115): V-VI               |
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10 Appendix A

See Table 3.

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Declarations

Conflict of interest The authors declare that they have no conflicts of interest to report regarding this study.

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