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Challenges and Opportunities in the Internet of Intelligence of Things in Higher Education—Towards Bridging Theory and Practice

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Abstract: The application of the Internet of Things is increasing in momentum as advances in artificial intelligence exponentially increase its integration. This has caused continuous shifts in the Internet of Things paradigm with increasing levels of complexity. Consequently, researchers, practitioners, and governments continue facing evolving challenges, making it more difficult to adapt. This is especially true in the education sector, which is the focus of this article. The overall purpose of this study is to explore the application of IoT and artificial intelligence in education and, more specifically, learning. Our methodology follows four research questions. We first report the results of a systematic literature review on the Internet of Intelligence of Things (IoIT) in education. Secondly, we develop a corresponding conceptual model, followed thirdly by an exploratory pilot survey conducted on a group of educators from around the world to get insights on their knowledge and use of the Internet of Things in their classroom, thereby providing a better understanding of issues, such as knowledge, use, and their readiness to integrate IoIT. We finally present the application of the IoITE conceptual model in teaching and learning through four use cases. Our review of publications shows that research in the IoITE is scarce. This is even more so if we consider its application to learning. Analysis of the survey results finds that educators, in general, are lacking in their readiness to innovate with the Internet of Things in learning. Use cases highlight IoITE possibilities and its potential to explore and exploit. Challenges are identified and discussed.

Keywords: higher education; IoT; intelligence; learning; systematic literature review; use

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1. Introduction

The world of Internet of Things (IoT) today is increasingly immersed in the digital innovation paradigm. Consequently, systematically transforming the spheres of information, technology, innovation, and management into a unified view, blurring all divides. Profound and fundamental changes in the way we do business and live our daily lives are felt across the globe. Products and services connected to devices and information systems communicate with people and with each other via real-time data, information, and intelligence around the clock [1].

Digital innovation gave rise to the Internet of Things, which, in turn, allowed the creation of smart entities (objects, software, cities, etc.). The IoT gained particular interest in the past decade, with researchers and practitioners exploring every aspect of its application. The IoT can be viewed as the aggregation of several digital innovations, such as blockchain, big data, cloud computing, sensors/effectors, and artificial intelligence, into one integrated cluster [2]. The IoT phenomenon, as an implementation platform for digital innovation, is driven by the needs of organizations, institutions, and governments to build connective capacity and to intelligently develop, adopt, adapt, and sustain innovations as part of their overall strategy, processes, operations, policies, and governance, with the goal to enhance and improve efficiencies and knowledge processing [2,3].

With the IoT aiming to control the physical world via interconnected smart objects [4], the notion of intelligence integration in the IoT is a significant advancement that has the potential to solve many challenges inherent to the IoT ecosystem. With the concept of intelligence-integrated IoT, the Internet of Intelligence of Things (IoIT) has become a novel IoT paradigm [5]. Considering the scale of the internet today and the corresponding enormous amount of data exchanged every second, one can only imagine the need for intelligence support to manage all the IoT elements. The fifth generation (5G) global mobile telecommunication standard has significantly reduced the processing speed gap between machines, objects, and devices, and with 6G, collective intelligence becomes a reality [6].

With the IoIT paradigm, intelligence takes center stage. Intelligence has been defined in many ways that include notions, such as logic, abstract thought, understanding, self-awareness, communication, learning, having emotional knowledge, retaining, planning, and problem-solving. Intelligence is being integrated into the IoT on a regular basis and empowering it to increasingly transform our surroundings, affecting the functions of people, organizations, institutions, and governments alike. Ref. [7] provides a new harmonized classification model of intelligence for the IoT. He identifies four levels at which intelligence may occur, namely data collection, data processing, communication, and decision-making. Consequently, we see today artificial intelligence moving from central servers to the edge of the IoT and closer to the 'things', such as mobile devices, thereby creating a new paradigm of 'edge intelligence' [8].

The higher education sector, and the focus of this study, has tremendous benefits in applying the IoIT to its administrative and management processes as well as to its adopted learning strategy. Online learning, or eLearning, remains very strong as a discipline of study and application, even more so since the onset of the COVID-19 pandemic. Unfortunately, the concept of online learning has not evolved much since then. This is true even though there are more digital innovations at the disposal of institutions and professors. The challenge of not having these innovations properly exploited persists. However, expected learning efficiencies still have not been adequately realized [1,9,10].

In general, the extent of use of information technology (IT) in higher education today has plateaued and advances at a snail's pace. Academic institutions and professors are lagging other industries in their utilization of IT as part of their integrated administrative processes and, more importantly, their teaching and learning strategy. Most professors in higher education institutions still use IT mostly to process documents. The notions of integration of different ITs and artificial intelligence for teaching and learning are scarcely entertained and properly supported by higher education institutions. When the IoT in all other sectors has taken root, only a few have begun to experiment with the integration of artificial intelligence in the context of higher education teaching and learning. Our study herein runs along the same vein and contributes to the work of these researchers interested in exploring and exploiting artificial intelligence integrated IoT in higher education teaching and learning.

Interest in the implementation of the IoT in the education sector by researchers, practitioners, and administrators is only recent. Although still in its early stages, all stakeholders in the education sector have begun to realize that a global paradigm shift in the education system is inevitable—key drivers being digital innovations such as blockchain, IoT devices, artificial intelligence, and COVID-19. However, significant challenges exist in relation to the implementation of IoIT in higher education and entail primarily educator's readiness, institutional capabilities, implementation costs, and lack of adequate digital strategy. IoT considerations will eventually reshape instructional systems and will allow for more personalized learning strategies and better responsive usage of learning settings [11].

A quick review of the literature shows that the IoIT is a novel concept, in general, and in higher education, published studies are scarce. Consequently, the purpose of this study is to better understand how IoIT may be applicable to higher education, in general, and the learning environment specifically. Based on the above, we posit the following research questions:

RQ1: *What is the current state-of-the-art in relation to the integration of intelligence in the IoT for education?*

RQ1 is addressed by performing a systematic literature review (SLR), allowing us to explore the body of literature from the broad perspective of IoT, followed by the integration of intelligence into the IoT, then, to more specific publications on IoIT in education.

The outcome from RQ1 entails adopting a set of relevant publications utilized to develop a conceptual model for IoIT in education. This conceptual model would identify the tiers, components, and their relationships in the context of education and leads to the second research question.

RQ2: What are the principal components of an IoIT architecture for education?

Basically, the conceptual model aims to show the IoIT-related components and their relationships, adapted to the specific context of higher education teaching and learning. The conceptual model provides researchers and practitioners with an overarching view as well as more details of different perspectives that they need to consider to achieve their IoT-integrated educational goals. However, practitioners, such as professors today, may neither have the knowledge nor the readiness to explore and apply the opportunities available for them by the IoIT. This leads to our third research question.

RQ3: To what extent are practitioners ready to implement IoIT in their teaching and learning activities?

To that effect, we conduct a pilot survey to obtain feedback from practitioners on their readiness for IoIT implementation, which is evaluated based on their self-assessed knowledge of IoIT and their use and experience of IoT in their practice.

Based on the analysis of the above three research questions, it becomes evident that specific applications of IoIT to teaching and learning are limited and need to be elaborated. Therefore, our fourth research question aims to address the application opportunities of IoIT in education, hence the fourth research question.

RQ4: What are the various elements of intelligent teaching and learning and how can they be applied?

This paper is divided into seven sections, as illustrated in Figure 1. After the introduction (Section 1), we present our systematic literature review (Section 2), where we introduce the details of our approach, followed by the analysis of the results (RQ1). Section 3 entails the development of the conceptual model for IoITE (RQ2). The exploratory pilot survey that we conducted to assess the readiness of practitioners for IoIT implementation in their teaching and learning is elaborated on in Section 4 (RQ3). In Section 5, we outline in more detail how the IoITE can be applied to education and learning (RQ4) and provide two use case scenarios (education and learning) each elaborating on two use cases, one in detail and another in brief. The two learning use cases have been partially implemented. Section 6 addresses the challenges and opportunities, including a discussion on relevant issues, while in Section 7, we present our conclusions, which synthesize our findings and elaborate on the relevance of the study. This article contains many acronyms that we cannot avoid, and therefore, we provided a list of abbreviations at the end.

Section	Description	Sub-Sections
Introduction	Background of subject area describing issues related to IoT and artificial intelligence in education. Formulation of four research questions (**RQ1 to RQ4**).	Background Research questions formulation
Systematic Literature Review	Details to the literature review approach and bibliometric analysis showing the scope of research and extant literature in IoT, IoIT and in our specific area of study IoITE. **Research Question 1**	Details to research approach Bibliometric analysis [IoT, IoIT, IoITE]
Conceptual Model	Development of the conceptual model for IoITE which includes the building blocks and the contextual views of IoITE. **Research Question 2**	Building blocks Contextual view of IoITE
Exploratory Pilot Study	A survey methodology was followed to capture and analyse participant's knowledge of and use of IoIT in Education. Participants were educators from different countries. **Research Question 3**	Methodology Results and analysis
Application of IoITE	Included two case scenarios namely classroom management and learning. Each scenario included one detailed and one brief use case. **Research Question 4**	Use Case Scenario 1: Education Classroom management Proctoring exams Use Case Scenario 2: Learning Game-Based AI-Assisted online discussion
Challenges & Discussion	This section identifies three challenges inherent to the IoT and artificial intelligence and three primary barriers to its application in the educational and learning sector.	
Conclusions	Study was summarized. Limitations of the study were identified. Implications to practitioners and higher education institutions were elaborated, and suggestions for future research discussed.	

Figure 1. Illustration of the paper structure.

2. Literature Review (RQ1)

2.1. Systematic Literature Review

The review of the body of knowledge relevant to this study is based on the outputs of different searches and data collected from Web of Science (WoS), Google Scholar, and Scopus. The output results were based on articles and conference proceedings alone. The literature review search results were analyzed according to keywords in the title of the articles. We followed a Systematic Literature Review approach similar to [12,13] despite our initial exploratory findings that the field of our current study of interest (IoITE) is narrow.

The SLR approach followed in our study was adapted from others in the field [14,15], with small changes to suit our context. Hence, we will not repeat the SLR details herein but summarize them in Table 1. We identify six steps in the SLR, namely, concept coding, scoping, concept search plan, inclusion/exclusion criteria, refinement, and analysis of the final retained set of articles (more details are available in [16]).

The aim of concept coding is to make a broad search to identify all possible key terms of interest, giving us a map of the concept structures and relationships. Our aim is to formulate a coding of key terms representing the concepts to be utilized in the detailed search. The word 'intelligence', for example, added to the IoT would result in many articles not related to education, with most of the articles found in the areas of computer science and engineering.

Table 1. Steps of the SLR.

Steps	Description	Purpose
Concept Coding	Broad search	Identification of key terms
Scoping	Identifying the boundaries of key terms	Delimiting keywords
Concept Search Plan	Developing a strategy for searching	Specifying search steps
Inclusion/Exclusion	Establishing and applying a set of criteria to apply search results	Filtering search results
Refinement	Reading articles in full and further consideration to retain or not	Selecting final set of articles
Analysis	Processing retained set of articles for insight and building on the work of previous researchers	Bibliometric analysis

In terms of delimiting the boundaries of our keywords' scope, IoT alone resulted in many articles. In our SLR strategy, we utilized the WoS (cross-examined and confirmed with google scholar and Scopus) to conduct the in-depth and more specific search, namely on the Internet of Things, then added the term 'Intelligence', and then added again the term 'Education' with the logical parameter 'AND'. We also replaced 'Education' with 'Learning' in different searches to ensure that we capture all possible research of interest.

Subsequently, our next step was primarily focused on article reduction (by applying different filters sequentially) and final cleanup, thereby leaving only the articles suitable for analysis. We limited our initial search results to articles published in peer-reviewed journals and conferences. We then excluded any articles that were in the areas of computer science and engineering, and we kept articles that dealt with the application of IoT in education, education management, cases and/or technology applications. When we replaced the word 'Education' with 'Learning', the results were not useful since all were in machine learning or similar technical areas.

The final set of articles for synthesis and analysis was read completely to see if they were deemed fit for our research goals. Although we retained some articles in machine learning, we did so because they were useful for our study as they included some architectural schemas that would help us adapt our IoITE conceptual model. Moreover, we found less than 10 articles when our search parameters included 'internet of things' + 'intelligence' + 'education'. This small number of articles would not be sufficient for our study purpose, thus, we continued our SLR by looking at the literature with 'internet of things' AND 'education' (filtered for 'intelligence') AND 'education' within the articles, as we reviewed their text in its entirety.

2.2. Bibliometric Analysis

The scope of publications in the IoIT in education was done by following a funnel approach. First, we conducted a broad search for publications in the 'IoT', followed by 'IoIT', and then finally, 'IoIT' in 'education'. We present a summary of the results for IoT and IoIT, and in more detail, those for the IoITE. This approach is necessary to position the area of study within IoT and artificial intelligence and understand the scope of the research in IoITE.

To understand the extant work, we performed a series of search combinations with IoT, AI, and education. The list below provides the search formulations that were conducted in the SSCI database.

1	TS = (internet of things)	4574
2	AB = (internet of things)	3292
3	TI = (internet of things)	954
4	(TS = (internet of things) AND AB = (artificial intelligence))	487
5	((TS = (internet of things)) AND AB = (artificial intelligence)) AND AB = (education)	42

6	TI = (internet of things)	964
7	(TI = (internet of things)) AND TI = (artificial intelligence)	24
8	((TI = (internet of things)) AND TI = (artificial intelligence)) AND TS = (education)	0
9	(TS = (education)) AND TI = (internet of things)	47
10	((TS = (education)) AND TI = (internet of things)) AND ALL = (artificial intelligence)	2
11	((TS = (education)) AND AB = (internet of things)) AND ALL = (artificial intelligence)	41
12	(TS = (internet of things)) AND AB = (education)	256

2.2.1. The Internet of Things

This IoT search in the title shows that the most published WoS categories are in engineering/electrical/electronics and telecommunications research, followed by computer science information systems and computer science theory methods. From a total of close to 3292 articles (in the abstract), over 90% of the publications were in engineering, telecommunications, and computer science. Over time, interest in IoT research began to increase gradually in 2015, following a parabolic pattern and peaking in 2021, as shown in Figure 2 below.

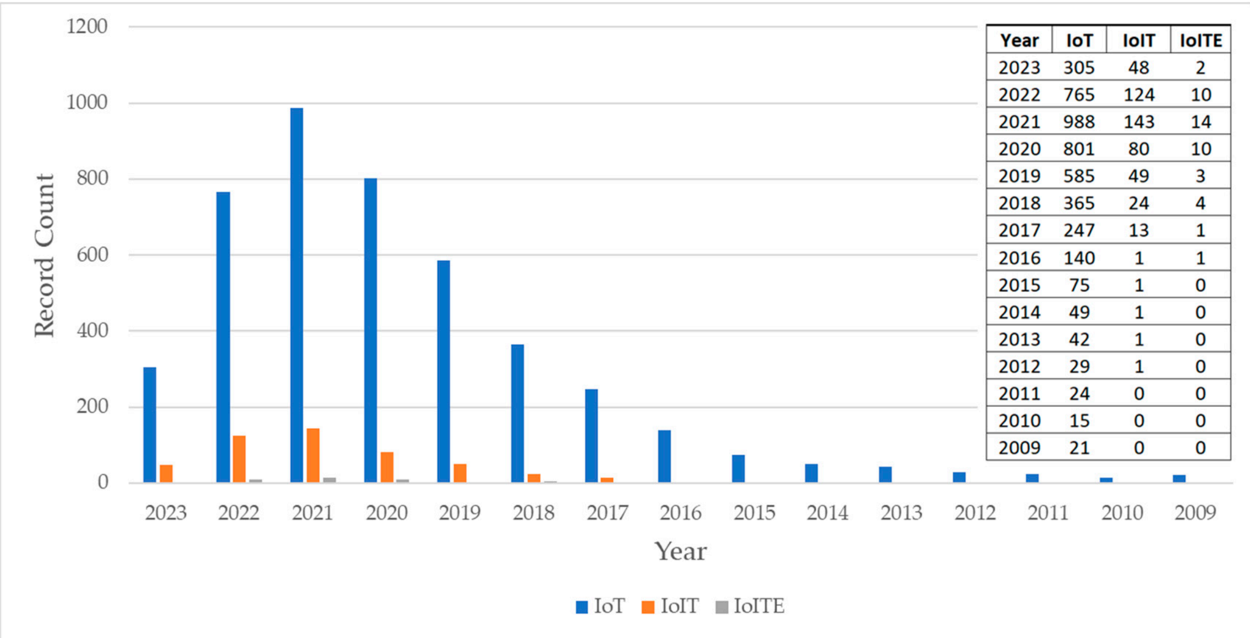

Figure 2. Publications record count in the past 15 years (excluding filtering and article reduction).

After previewing the literature, we observed that there does not seem to be a consensus on a general design, schema, or architecture of the IoT, and an accepted architecture or an acknowledged universal set of standards is not available. However, there are a few standardization bodies elaborating on IoT protocols, system components, and functional architecture [7,17]. Refs. [18,19] define the concept behind IoT as "the pervasive presence around us of a variety of things or objects—such as Radio-Frequency Identification (RFID) tags, sensors, actuators, mobile phones, etc.—which through unique addressing schemes are able to interact with each other and cooperate with their neighbors". Moreover, based on [7,20–25], the primary elements being namely devices, networks, computation, and platforms, that together constitute the IoT ecosystem, have been identified and elaborated in detail.

In their architectural reference models of devices for Internet of Things applications, ITU-T Y.4460 [20,21] define IoT as "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies".

In this article, we view the IoT "as an aggregation and consolidation of various technologies which may or may not have different types of intelligence, managing tangible and intangible artifacts, connecting with each other via a variety of communication gateways, to allow the exchange of data, information, and knowledge among its human and machine actors".

Further analysis of the IoT is outside the scope of this article, however, more information can be found in [26], who provide an excellent case study of how IoT can help knowledge management in the automotive domain, [7] includes a great section elaborating on what is Internet of Things, and [11] provides and elaborates on the definition of the IoT.

2.2.2. The Internet of Intelligence of Things

A search for publications containing 'internet' AND 'of' AND 'Intelligence' AND 'things' in their title revealed that relatively few research studies (compared to IoT publications) have been done on artificial intelligence and the IoT. Compared to IoT, by filtering those who studied the different notions of intelligence, 186 articles were found. With artificial intelligence research increasing dramatically in the last couple of years (see Figure 2), there seems to be a significant gap regarding studies on its integration with IoT. The prominent WoS categories remain in engineering/electrical/electronics and telecommunications research, with a combined published works of 76, followed by computer science information systems (52 articles) and computer science theory methods.

We reviewed the relevant literature on IoIT and presented in Figure 3 a consolidated view of the IoIT architecture. The scientific literature tells us that the concept of IoT hyper-connectivity is the fundamental condition for intelligence to occur. All digital hardware such as smartphones, smart TVs, cameras, vehicles (airplanes, trains, and automobiles—guided and auto-guided), laptops, tablets, wearables, and other equipment have connectivity components integrated into their designs to send and receive information with each other and the rest of the world. Geolocation components/interfaces such as RFID can be easily added to the "things not yet digital" equipment [25]. At the same time, processing power continues to increase exponentially, and combined with the hyper-connected IoT, we find ourselves in the arena of big data and intelligence processing.

Ref. [7] suggests that for intelligence to be possible in "Things" in the IoT, four layers need to exist, namely, device, network, service, and application layers. He suggests that the intelligent facet and limits of the IoT aree not clearly defined in the body of knowledge. In fact, the IoT is an amalgamation of different works, such as data mining, context awareness, artificial intelligence, big data, ambient intelligence, and semantic reasoning, among others. Therefore, it seems that as the IoT evolves, an increasing number of elements combined build opportunities for the creation of different types and levels of intelligence.

Based on the development of intelligence for the IoT by [7,27] and synthesis of the literature from our SLR, we find that five visions (in the same vein as [7,27]) can be derived (see Figure 3): (1) Intelligence throughout a Network, "Intelligence of Nets" (IoN) [20], (2) Intelligence of Systems [28], (3) Intelligence of Devices (IoD), (4) Intelligence of Platforms (IoPF—a new addition), and (5) Intelligence of People (IoP—a new addition). We intentionally use the term "platform" to align our work with emerging research in digital innovations and platforms.

It is worthwhile noting that the International Telecommunication Union [20], which is the United Nations specialized agency for information and communication technologies (ICT), introduced the IoT as a key technical vision, thanks to its ubiquitous networks driven by enabling technologies (including RFID, sensor technologies, smart things, nanotechnology, and miniaturization), and ubiquitous computing. In other words, the inter-connectedness of the above-mentioned intelligence visions, namely that of networks, systems, devices, platforms, and people, represent a unified vision that is, as they referred to it, 'ubiquitous' (universal, pervasive, and persistent). This view is elaborated on schematically in Figure 3, showing the interactions of these intelligences across the IoT architecture.

The state of these intelligences today seems to be at its infancy despite new enabling technologies, such as blockchain and generative AI, and there is still much to be studied and learned to help guide its future ambidexterity and methods to support humanity.

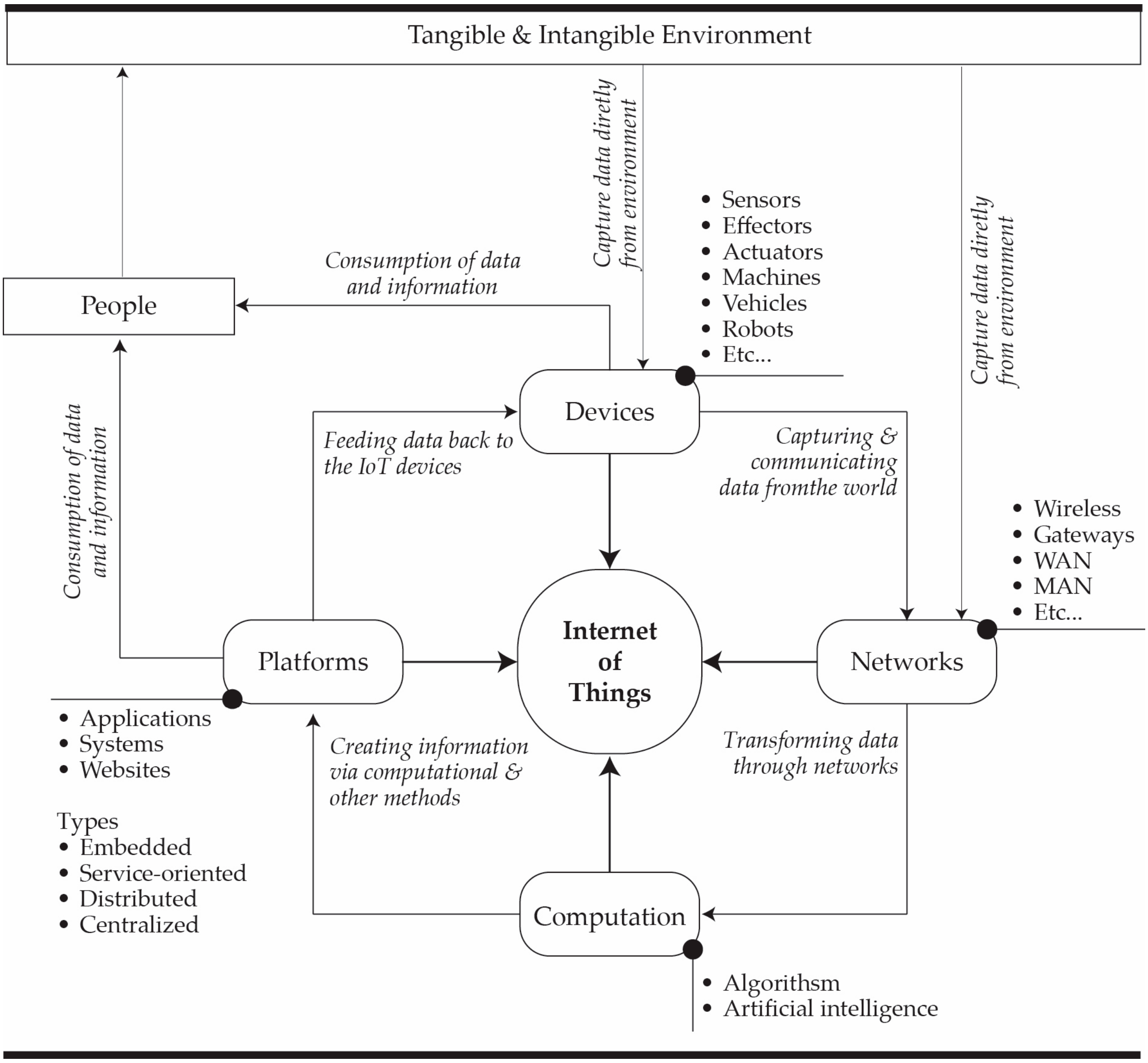

Figure 3. Consolidated view of IoIT conceptual architecture.

2.2.3. The Internet of Intelligence of Things in Education

As a final part of our literature review, we focused on publications that report on studies related to the application of IoIT in the higher education sector, in general, and more specifically, on studies that address learning. Consequently, we added to the previous IoIT terms the keyword 'education'. In the same vein as the previous two searches of IoT and IoIT, the WoS gives 42 articles. To be more accurate, on the scope of our current study, our interest lies in higher education as it is transformed by the Intelligence of Things. Due to the relatively few published research papers on IoITE, we performed our literature review analysis on the body of research in IoTE. Our literature search resulted in 256 articles, of which 29 are in education. Interest in the IoITE increased in 2020, 2021, and 2022 with 10, 14, and 10 publications, as shown in Figure 2 above.

It is clear from these results that there is relatively very little work being done on the application of the IoT in the education sector. However, the ubiquitous presence of IoT devices in other industries puts pressure on academic institutions to adapt and adopt the IoT paradigm [29]. In their article, they attempt to summarize and categorize the benefits and challenges of IoT in pedagogical processes for all educational actors, including faculty, students, and staff, and provide a framework to position and facilitate research activities. Their structured literature review on IoT applications in the education sector produces 106 articles that report on specific applications of IoT.

Through detailed analysis of the adopted set of publications, we were able to identify two recent and most relevant studies that deal with the application of IoIT in education, namely smart campus [30] and wearable computing in education [31]. Ref. [30] address the problem of declining classroom attendance and the use of classroom time with the help of IoT sensors. Their study aims to utilize IoT sensors to facilitate and optimize the diverse demands for enhanced student time management via predicting attendance, optimal allocation of rooms, and space use wastage. Their study demonstrated a ten percent enhancement of room costs and a significant decrease in room overflows.

Moreover, [30] studied the application of the IoIT on operational aspects of education, [31] addressed the issue of using IoT, and more specifically wearable devices, to increase their use for improved teaching and learning. Their research included the identification of 107 papers retained for their analysis. All these articles were in relation to the application of wearable devices to capture data, namely physiological and behavioral, for educational purposes. The purpose is to support student's learning and teacher's delivery, management of campus facilities in general, and services to special groups, such as students with learning difficulties. However, the scope of their study did not consist of the use of intelligence in the application of wearable devices.

It is evident from the foregoing that research work on the integration of intelligence in IoT and its application in the education sector, specifically to teaching and learning, and as expressed by [31] as well, is scarce. Moreover, recent research works [29–31], including the current literature review findings, agree that IoITE is in its early stages of development.

Table 2 lists the 18 articles retained for analysis and used for the development of the conceptual framework and illustrative use cases. In Table 2, we present the article reference, the area of research, the digital innovation that the article studies, and whether it specifically addressed learning (italicized). Out of the 18 articles, three were around computer science/engineering, four dealt with economic considerations of education, three were management/business-oriented, one on professor perceptions, and five addressed learning. Moreover, only one was in the higher education context.

Table 2. Articles retained for analysis after the SLR.

Article	Areas	Digital Innovations
1. [31]	*Education*	*Wearable computing*
2. [32]	Management on campus	Information system
3. [33]	Professor perceptions	N/A
4. [34]	*Social learning theory*	*Intelligence*
5. [29]	Education; Systematic literature review	N/A
6. [35]	Business process (academia)	Blockchain

Table 2. *Cont.*

Article		Areas	Digital Innovations
7.	[36]	Education	AI
8.	[30]	*Education; Smart Campus; Classroom*	*IoT and AI*
9.	[37]	*Learning*	*Digital platforms*
10.	[38]	*Education; Decision-making*	*N/A*
11.	[39]	Economy; Education	BD; AI; ML
12.	[40]	International economy; Education	Blockchain; AI
13.	[41]	Education; Economy	BD; A; ML
14.	[42]	*Computer science; Engr; Education*	*Voice assistant; AI*
15.	[43]	Business Model; Education	N/A
16.	[11]	*Education*	*N/A*
17.	[44]	*Higher education*	*N/A*
18.	[45]	Architecture; Academia; Software engineering	AI; Distributed computing

Building on the insights and findings of the SLR, and based on Figure 3, the five intelligence visions (networks, systems, devices, platforms, and people) were adapted to build a conceptual model for IoIT in education (management in general and learning in specific). Figures 4 and 5 represent the building blocks and conceptual view of IoITE, respectively. Figure 4 reinterprets a general IoIT view of Figure 3, revealing the layers that need to be part of the institutional digital strategy necessary to realize the IoIT. In general, Figure 4 shows the points of interactions between the different blocks and serves as the middle architectural schema linking the general IoIT design (Figure 3) with its application to IoITE (Figure 5). Subsequently, Figure 5 orients the building blocks (excluding digital infrastructure) around the layers of data, information, knowledge, and intelligence, showing the processing that occurs across each layer. The next section elaborates on these concepts in more detail.

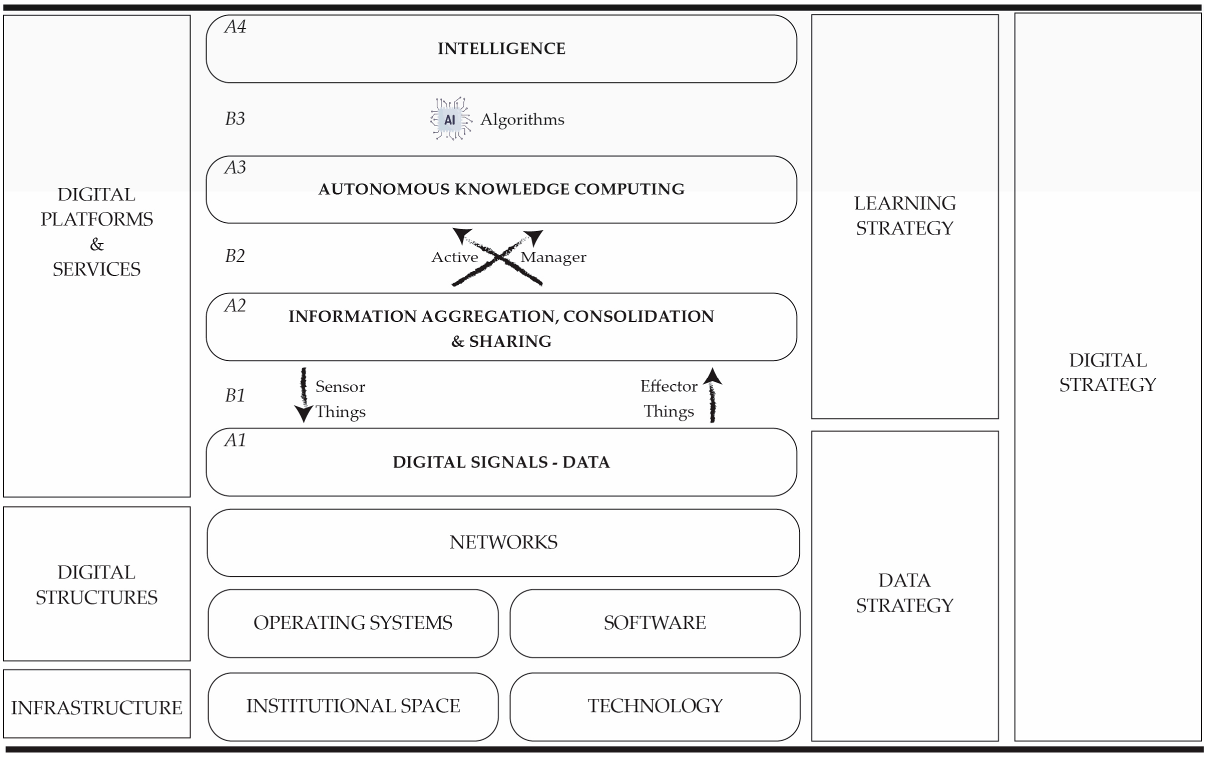

Figure 4. Building blocks of intelligence-integrated higher education institution.

IoIT Visions [Technical Layers]	**Intelligence [AI Layers]**	**Intelligence [States]**	**Subject Matter [Knowledge Processing]**
1. Learning/Educational Services	Smart Platforms Delivery *(AI-Supported teaching & Learning Methods)*	Learning Context *(AI-Supported teaching & learning methods) Context Aware* ǀ *Accurate/Actionable* ǀ *Ineractive* ǀ *Individualized*	Intelligence *IoIT of People*
2. Computational Systems	Learning Analytics, AI-Enabled *(AI-Supported Learning Data Capture)*	Automated Teacher & Students Delivery *(Purpose-oriented information processing) Self-Organizing* ǀ *Credible Virtualization* ǀ *Crowd Information*	Knowledge *IoIT of Systems & Platforms*
3. Networks	Hypersharing *(AI-Supported Interactions)*	Ubiquitous Learning Data Capture *(Real-time and smart data-oriented processing) Relevant* ǀ *Secured Batch/Real-Time* ǀ *Tacit/Explicit*	Information *IoIT of Networks*
4. Devices (Sensors/Effectors)	Smart Devices *(AI-Supported Edge Computing)*	Multisource & Edge Computing	Data *IoIT of Devices*

Figure 5. Contextual View of IoITE Conceptual Model.

3. Development of Conceptual Model (RQ2)

In our development of the conceptual framework, we adapted IoT and artificial intelligence models to the higher-education context, including people, learning objects, and intelligent systems. Our conceptual model is based on the connectedness of intelligence in the IoT paradigm [46,47] and entails first the schematization of the IoITE building blocks, followed by a contextual view of the IoITE. Tangible and intangible educational assets are aligned with the traditional IoT conceptual models, thereby providing a map of components necessary for the realization of the IoITE. Building blocks for IoITE include infrastructural components, active devices, process management, algorithms, and strategic elements.

The Internet of Intelligence of Things is a concept based on the interconnectedness of objects, electronics, software, and connectivity to interchange data and information. In the educational context, this view of "Things" that are connected/networked to "People (Professors, Students, Staff)" and "Educational Objects (eBooks, Smart Boards, Software, Games, Apps, Wearables, Mobile Phones, Tablets, etc.), while being managed by software technologies, can be extended to the concept of "smart education". In this case, objects have active sensory abilities to receive, process, and send educational-related data without human intervention and with the following objectives: to improve the quality and standard of education and learning, empower the academic stakeholders, namely the professors, students, and staff, simplify the complexity of the educational system, and enhance the learning experience. We can expect that with the connectedness and intelligence in the IoIT paradigm, it would only make sense to create an intelligent educational ecosystem that is smart and efficient (like a smart city, [46])—hence the smart university, or Smart Higher Education.

3.1. Building Blocks of IoITE

Figure 4 presents an integrated view of tangible and intangible building blocks for the IoITE aligned with the basic conceptual model of the IoT described above. Figure 4 shows the mapping of components for the realization of the IoITE, starting at the bottom with infrastructure as the foundation and ending at the top with intelligence processing and management. Of course, one expects that all universities have infrastructure, physical and digital, but the question is whether they are IoT-ready or not. More importantly, if we consider low-income countries, the level and standard of the university's digital infrastructure may not be up to date and may have many challenges in terms of required investments.

The level of digital infrastructure is represented on the right-hand side of Figure 4, where all the 10 layers of the schema are addressed in an institutional "Digital Strategy". Many institutions may have devised digital strategies, but they most probably lack from being complete, comprehensive, innovative, and forward-thinking, simply because institutions built or updated their digital strategies as a reaction to the COVID-19 conditions and were rushed into it to ensure the sustainability of its operations. An important part of the comprehensive digital strategy is the data and learning strategies, which include four and six layers, respectively.

3.2. Contextual View of IoIT in Education

In Figure 5, we present the contextual view of IoIT in education based on Figures 3 and 4. Figure 5 shows a four-by-four matrix representing the IoITE. At the top, the components are identified, namely technical, intelligence, state, and knowledge. Each component is broken down into four layers whereby each layer aligns the functions of the components. From a technical perspective, the layers from bottom to top are sensors (to capture data), networks (to communicate the data), computation (to process the data), and services (to make sense of the data).

As mentioned earlier, intelligence is a notion of opportunity found in all components and layers. Therefore, it can be embedded in SoT and EoT, in networks via hyper-sharing, by artificial intelligence computations, and smart platforms. The application of intelligence at every layer creates an intelligence state, namely multisource, ubiquitous, automated, and contextual. At the data level, intelligence can be applied to manage relevance, security, time-related processing, and tacit/explicit data. Through these functions, data can be processed into information that is usable and meaningful, making the intelligence state ubiquitous. Through self-organizing, digital innovations, such as blockchain, virtualization, and crowd engagement, information can be converted into knowledge that is actionable. With automation potential, situational awareness, accuracy validation, and individualization, the entire IoITE ecosystem can be brought into a smart context.

4. Exploratory Pilot Survey Study (RQ3)

4.1. Methodology

A survey methodology approach was followed using the questionnaire presented in Table 3 below. The online survey tool utilized in this study was 'survey monkey', which enabled us to ensure confidentiality and quickly distribute it to participants via a link and manage surveys in a cost-effective and time-efficient manner. The survey link was sent to 37 potential participants across eight different countries. The questions in the survey were adapted and expanded from other research studies.

Table 3. The IoT survey in the context of education.

In the following questions, "education" implies all university functions (administrative, facility, management, classrooms, laboratories, computers) and learning processes (in class), and "IoT" refers to the Internet of Things in terms of devices and applications, including intelligence, and the use of mobile devices, laptops, wearables, smart classes, smart campus.
Examples:

- Use of smart digital whiteboard in class
- Electronic books and other learning resources
- Use of artificial intelligence tools for learning
- Animations, videos, simulations, virtual reality, augmented reality, etc.
- Use of learning management system
- Smart facility controls, such as classroom environment management for light, noise, temperature, and other
- Physical space access controls,
- Attendance tracking,
- Matching students for peer learning,
- Use of messaging to get information from university administration related to your academic account or important information, such as for crisis management,
- Text messages for classroom learning purposes support learning, including messages from professors about course-related activities and announcements,
- Using devices to enhance student engagement,
- Using devices to enhance access to professors and tutors.

In the following questions, we implicitly refer to IoT as IoT devices, applications, and intelligence. Therefore, whenever the word IoT appears, it refers to IoT devices, applications, and intelligence, as elaborated in the list above.
How much do you feel you understand the following concepts?
[Scale: Not at all, Not Well, Neutral, Well, Very well]

IoT devices	Cloud computing
IoT applications	Cryptocurrency
Data science and& analytics	Sensors and& actuators
Artificial Intelligence	Blockchain
Digital innovation and transformation	

Which of the following IT TOOLS have you used in education and/or for learning?
[Scale: Always, Very Often, Sometimes, Rarely, Never]

Learning management systems	Online government portal
Messaging from your institution	Digital whiteboard
Streaming videos	Electronic readers
Video conferencing/meeting	Artificial intelligence tools
Digital books	Animations
Smart phone	Augmented reality
Wearables such as smart watch	Massive Multiplayer Online Role-Playing Game (MMORPG)
Text messaging	Attendance tracking
COVID-19 Tracker app	Online peer- to- peer learning
Notebook/iPad	Smart apps~geospatial tracking
Simulations	Smart tutoring systems
Smart facility controls	Cryptocurrency
Physical space access controls	

The survey started with a short opening statement explaining the research setup, including its purpose, survey guidelines, confidentiality and ethics, their rights to ask any questions of concern, the participant's right to withdraw at any time, and an offer to leave their email if interested in seeing the results when available. The survey included demographic questions, namely regarding gender and language spoken, an explanation of what is meant by education and IoT in our survey questions, and two grids, one regarding the level of understanding of IoT, and the other about the use of the IoT in learning. Anonymity was guaranteed to all participants by not capturing any data that could identify them.

A 5-point Likert scale was used with anchors from "always" to "never" for usage and from "not at all" to "very well" for self-assessed knowledge. We attempted to get as diverse perspective as possible to the participants who were from South Africa, Australia, Bulgaria, Egypt, Italy, Jordan, USA, Canada, and China.

4.2. Results and Analysis

Table 4 presents the results of the participant's self-assessed knowledge of nine IoT concepts. Out of 37 participants, 28 provided complete and usable responses. All participants were professors from higher education institutions, one was a dean, and the rest were either part-timers (who also give training in the United Nations) or full-time tenured or tenure-track. The professors came from different backgrounds including law, business, engineering, computer science, and economics. Sixty-five percent of the participants were male, and 54% reported English to be their spoken language. Forty-six percent of the participants spoke Chinese and Arabic. However, these numbers are not accurate because we know that some of the contacted participants were in Italy and Morocco.

Table 4. Self-assessed knowledge of IoT concepts (N = 28).

IoT Concepts	Not at All	Not Well	Neutral	Well	Very Well	Average *
IoT devices	0	8	8	60	24	4.00
IoT applications	0	8	12	60	20	3.92
Data science and analytics	4	8	16	40	32	3.88
Artificial Intelligence	4	16	20	40	20	3.56
Digital innovation and transformation	4	12	24	44	16	3.56
Cloud computing	4	28	8	28	32	3.56
Cryptocurrency	8	28	12	40	12	3.20
Sensors and actuators	12	24	24	24	16	3.08
Blockchain	20	16	20	32	12	3.00

* On the last column, to the right, we present the weighted average and sort it by decreasing order.

Table 4 shows that around 80% of the participants feel that they understand the concepts of IoT devices and applications well or very well. Although this is encouraging, when asked about detailed components of the IoT, only around 70% (data science and analytics), 60% (artificial intelligence and digital innovation and transformation and cloud computing), 50% (cryptocurrency), and 40% (sensors and actuators and blockchain) reported to understand them at the well and very well levels.

It seems that educators understand the overall notion and basic concepts of the IoT but not its details. This is not sufficient for IoT implementation in education because educators unless they understand the details, will not be able to be ambidextrous (explore and exploit) with the full range of IoT capabilities. This is especially true when intelligence is a significant part of applying the IoT, and yet adds a new level of complexity to its use by educational institutions. This is confirmed by the literature, where most of the research in education is still in technology-enabled content management. The only exception may be in computer science and engineering courses, while in other disciplines, IoT is virtually non-existent. Nevertheless, even in computer science and engineering, the application of IoT is so specific to a highly customized single learning activity that the methods used are not applicable elsewhere.

Table 5 shows the participant's responses on their use of 25 IoT applications in education. We feel that for an educator to apply IoT in their educational design, use of devices, software, and intelligent tools can be a critical indicator of their capacity and capabilities to configure them for learning. It is expected that the more the educator is familiar with IoT use, the more they are willing to explore and exploit opportunities for IoT-driven learning (this is conditional to the digital strategy and regulations of the institution).

Table 5. Survey questions on how often they used the following for educational purposes.

IoT Tools	Always (%)	Very Often (%)	Sometimes (%)	Rarely (%)	Never (%)
Learning management systems	43	18	25	0	12
Messaging from your institution	35	35	14	7	7
Streaming videos	25	37	18	18	0
Video conferencing/meeting	22	55	11	5	5
Digital books	20	40	13	6	20
Smartphone	10	40	25	25	0
Wearables such as smartwatch	12	6	0	12	68
Text messaging	14	28	14	28	14
COVID-19 Tracker app	12	12	0	6	68
Notebook/iPad	6	20	40	20	13
Simulations	7	23	38	15	15
Smart facility controls	8	8	16	8	58
Physical space access controls	8	16	16	8	50
Online government portal	7	7	7	0	76
Digital whiteboard	0	21	14	28	35
Electronic readers	0	7	7	7	78
Artificial intelligence tools	0	8	25	25	41
Animations	0	21	21	28	28
Augmented reality	0	7	23	7	61
MMORPG	0	7	7	0	84
Attendance tracking	0	33	25	8	33
Online peer-to-peer learning	0	42	19	28	14
Smart apps~geospatial tracking	0	15	7	23	53
Smart tutoring systems	0	23	23	30	23
Cryptocurrency	0	15	7	7	69

Table 5 presents the results in decreasing order of "always" responses. We also highlight in bold some noteworthy results. As expected, most participants reported using the learning management system sometimes, very often, and always. However, only close to 43% reported using it always. This is rather disappointing, and a much larger survey is necessary to obtain a better perspective of this. Surprisingly, some limit their use of learning management systems only to share content and not use it in a more IoT-enabled way. We also notice that video conferencing, digital books, and smartphones are often used (40–55%). Around 69% reported never using wearables and COVID-19 tracker applications, and close to 76% never used government online portals or electronic readers (78%). Fifteen out of the 25 IoT tools were never or rarely used in an educational context by 50% or more of the respondents.

5. Application of IoIT in Education (RQ4)

The insights shown from the conceptual model and findings provided by the exploratory pilot study are then utilized to illustrate how the IoITE can be realized—noting that the full potential and use of the IoITE elements would render a state-of-the-art application of today's innovations and that institutions are at a very early stage and at various degrees of IoT integration and IoITE realization.

We view administration, management, and learning within every institution as an integrated IoT micro-ecosystem to demonstrate the extent of applicability of IoIT in providing substantive functions and benefits to connect stakeholders. We later explore the use and knowledge of IoT tools by educators in their academic lives to obtain preliminary insights on issues and challenges related to the implementation of IoITE. In our case, the application of IoIT can occur in all the layers identified in the conceptual model and to different degrees, such as university physical infrastructure and access to facilities management, management and mobilization of resources, and learning [43].

The IoT with embedded intelligence can be applied to the entire inter- and intra-academic institution, which entails the capture of behavioral, physiological, and process data for intelligence computations. More specifically, we list in Table 6 (not in any specific order) some of the more important applications of IoIT in higher education institutions:

Table 6. Application of IoT on campus and in learning.

1. Websites that students and teachers visit.
2. Time spent on websites.
3. Energy management, such as heating and lighting that is different over time in different places of the campus. Can include climatological data, such as temperature, wind, and sun.
4. Ecosystem monitoring, such as environmental conditions of air quality.
5. Access control to offices, labs, and other facilities.
6. Specialized campus apps for digital interactions within campus community using communication tools, such as Messenger and WhatsApp.
7. Downloads and uploads of files (administrative, learning, teaching, operational such as appointments and wellness purposes) by students and faculty.
8. Monitoring in real-time of school email for educational purposes, such as students confused about a course assignment.
9. Time spent in classrooms.
10. Attendance monitoring and controls, such as reminders.
11. Intelligence analysis of attendance impact on performance and sharing results with students and teachers.
12. Frequency of study with classmates monitored as they meet in study rooms.
13. Lectures time analysis for optimal people flow.
14. Classroom allocation optimization.
15. Location tracking on school premises and analysis of proximity to others.
16. Pattern analysis on student physical clusters and behavior.
17. Using wearable devices for vital signs data capture, such as
    - body temperature,
    - heart rate in case of health-related events,
    - emotion recognition,
    - electro-cardiograms in case of health-related events,

    All of these can be used for indoor environmental quality, exam anxieties, and overall health status and well-being.
18. Number of steps tracking information for health purposes.
19. Automatic and systematic recording of classroom lectures.
20. Access to smartphone sensors while on campus for security purposes.
21. Time spent on campus for optimization of flow and physical capacity capabilities.
22. Classroom participation, engagement, and attention.
23. Using specialized wearable devices, self-improvement, and creativity.
24. Management of students with learning difficulties.
25. Special assistance education and management.

We can consider the scenario of a typical university, which has a reasonable infrastructure that will allow it to have enough capabilities to allow for IoITE implementations at all levels and conduct intelligent education/learning. In other words, we are looking at the "Smart University" where various IoIT implementations can be increasingly embedded into the education system for administrative, business process, pedagogical, facilities, and people management purposes. With more IoIT integration, the university becomes smarter and takes the form of a living biological (in the technology sense) ecosystem.

Ultimately, the education arena is a human-centered, intelligent, and highly contextual environment. The IoITE proposes an ecosystem of systems and intelligences, which can be represented by infospheres. We elaborate on our proposed design intelligence layers as follows [47]:

Smart devices (Multisource): Phenomenologically, smart devices behave intelligently and create meaning by artifacts–context–actor interactions from various relevant sources, whereby personalized relationships emerge. Artifacts can be any of the dimensions and factors listed in Table 7. Consequently, actors are empowered by extending their capabilities, enhancing the accomplishment of tasks, reducing errors, and streamlining the IoITE ecosystem.

Hyper-sharing (Ubiquitous): By establishing a hyper-sharing environment, actionable subject–object interactions arise whereby the coupling of abilities intermingle to constitute a new whole. Processes and experiences would flow unobstructed and in a timely fashion, enhancing efficiencies of the information communication architecture of the IoITE ecosystem.

Artificial Processing (Automated): Artificial intelligence and ubiquitous computations become simultaneously physical and local, digital, and global. Intelligence creates nodes represented as spheres of information and learning that are evolving, transient, timeless, and synchronous into a living network of intelligences.

Smart platform (Contextual): Artifacts, actors, and intelligences compose a contextual information-based smart platform (ecosystem) that is complex, consistent, conversational, and ontological. The smart platform is adaptable and manages processes with a purpose such that when actors change something, a SoT or EoT impacts the environment or updates an object (changed, introduced, or deleted). As such, the smart platform changes itself. In essence, the smart platform realizes the IoITE as it contextualizes the student's, teacher's, administrator's, and manager's academic experience.

Table 7 shows a morphological representation of the elements of an IoITE Smart Digital Learning Platform (SDLP) (an expanded adaptation from [48]), followed by Table 8, which maps those dimensions to the conceptual model representing the 5 AI visions. The table depicts the determinants for interactions in an IoITE-connected university as it applies to learning. This can be expanded to all other functions and facilities, such as physical space, administration, and management of resources. Focusing on the learning infosphere of the SDLP, we identify 16 dimensions listed in the first left-hand column and 100 factors associated with the different dimensions.

These factors can be viewed as determinants for the design of any IoT implementation via their combination. As discussed earlier, the possibilities are many, and the challenge complexity depends on the identification of needs and requirements. One can build an IoT implementation by combining any number of the 100 determinants to represent a certain pedagogy that is suitable for a specific learning goal. We can elaborate on the utility of Table 7 by expanding on four specific use case scenarios.

Table 7 can be utilized by practitioners to (1) be aware of the possibilities for IoT use in their classroom, (2) assess these possibilities against available resources, (3) finalize requirements, (4) design their course, and (5) map the educational activities, which includes pedagogy and assessment. The IoT toolbox available to them can then be integrated to help them achieve their goals. Below, we provide two scenarios (one related to educational management, and the other considers the learning process) on how Table 7 can be used via use cases that the authors had experienced over the past couple of decades when the IT in education paradigm was at its early development stages.

Table 7. Morphological representation of IoITE smart learning factors/dimensions (elements of intelligent teaching and learning).

Dimensions		**Factors/Determinants**		
1.	Communication Mode	Synch	Asynch	live
		Real-time	Batch	
2.	Interaction Types (Traditional)	Learner–Learner	Learner–Teacher	Learner–Content
		Teacher–Teacher	Teacher–Content	Teacher–TA
		Learner–TA	TA–Content	
3.	Interaction Types (IoITE)	Learner–Sensors-of-Things	L–Effectors-of-Things	Teacher–Sensor-of-Things
		Teacher–Effectors-of-Things	TA–Sensors-of-Things	TA–Effectors-of-Things
		Content–Sensors-of-Things	Content–Effectors-of-Things	Content–AI-Teachers
		Content–AI-Content	Content–AI-TA	Content–AI-Learner
		Learner–AI-Environment		
4.	Interaction Context	Inter-INST	Intra-INST	Regional
		National	INTL	
5.	Content type	Passive	Active	Adaptive
6.	Content creation	Socialization	Externalization	Internalization
		Combination		
7.	Content form	Tacit	Explicit	
8.	SoT	Alerts	Announcements	Due dates
		Proximity	Human flow	Attendance
		Location	Emotional Recognition	
9.	EoT	Tracking	Proximity	Emotional State
		Health	Learning state	
10.	eTools (IT-mediated)	Chat	Forum	Wiki
		Messaging	Blogs	Peer2Peer
		Collaboration	Multimedia	Competition
11.	eTools (Intelligent)	Adaptive	Recommendation	Automation
		Simulation	Customization	Agents
		Competition	Ambient	Distributed
		Auto Assessment	Planning	Gaming
		Experience Oriented		
12.	Levels of Intelligence (~data)	Collection	Transmission	Treatment
		State of notification	Decision-making	
13.	Levels of Intelligence (~System)	Distributed	Platform	SO
		Embedded	Context-Aware	
14.	Level of Intelligence(~Network)	Local	Global	Vertical
		Horizontal		
15.	Pedagogies	Behaviorism	Cognitivism	Constructivism
		Connectivism	Self-Directed	Hybrid
16.	Teaching and learning forms	Tutoring	Coaching	Mentoring
		Direct	Cooperative	Experiential

Table 8. Mapping of learning dimensions to conceptual model.

	IoIT of	Networks	Systems	Devices	Platforms	People
1.	Communication Mode	✓				
2.	Interaction Types (Traditional)	✓				
3.	Interaction Types (IoITE)	✓	✓			
4.	Interaction Context	✓				✓
5.	Content type				✓	✓
6.	Content creation				✓	✓
7.	Content form				✓	✓
8.	SoT			✓		
9.	EoT			✓		
10.	eTools (IT-mediated)		✓	✓	✓	
11.	eTools (Intelligent)		✓	✓	✓	
12.	Levels of Intelligence (~data)	✓	✓			
13.	Levels of Intelligence (~System)	✓	✓			
14.	Level of Intelligence(~Network)	✓	✓			
15.	Pedagogies				✓	✓
16.	Teaching and learning forms				✓	✓

We start with the first use case scenario in the educational context detailing the use case on how IoT can provide advantages and opportunities for overall classroom management, followed by a brief use case on the proctoring of final exams. The second use case scenario focuses on pedagogy and learning, namely detailing a use case on game-based learning, with an additional brief use case on intelligent peer-to-peer learning. We organize the detailed use cases into four sections, namely possibilities, requirements, design/configuration, and learning activities. Please note that these use case scenarios and sections are for demonstration purposes and are not intended to be fully developed. However, in real-life cases, each section will need to provide enough details for it to be feasible for implementation.

5.1. Use Case Scenario 1: Education:

5.1.1. Use Case 1—Detailed: Classroom Management

Delivering lectures is relatively easy for university professors as far as the subject matter is concerned. However, generally speaking, they are not trained or certified for instructional methods, pedagogy, and classroom management (since these are not usually requirements for hiring). Moreover, the notion of pedagogy in higher education is not applicable per se since the students are adults. Therefore, little, if any, is transferable from high school learning strategies to higher education. The IoT can help in meeting certain specific standard requirements from the higher education student, for example, time management and self-directed learning.

In this situation, artificial intelligence can support the professors in a number of ways where (for example) students can be initially assessed for (1) their knowledge of the course pre-requisites, (2) their existing level of knowledge of the course content, (3) their personality traits and aptitude for learning, (4) if there is an online component(s), then their readiness for and behavior towards online learning, and (5) their level of self-efficacy. For each of those assessments, the student would be placed in specific pre-determined clusters characterized by a specific level of AI support (for example: Requires a lot of support, moderate amount of support, little amount of support, and no support necessary). Accordingly, the AI would produce a set of resources and level of monitoring for each cluster, determining and deploying a set of support functions along the following parameters: alerts, supplementary content, risk category, professor communication, special pedagogy, and remedial learning activities. The AI can even go further to:

- place students in a classroom strategically,
- consider students' learning abilities (or disabilities that will affect the requirements of assignments and exams),
- monitor students' anxiety level via smartwatches,
- ping students in real time on whether they understand the lecture and if not, ask questions and connect to the professor's device to mitigate the progression of learning,
- propose a schedule for students' workload on the different assignments to meet deadlines and prepare for exams and
- match compatible students into special groups, such as study buddies and collaborative project work.

Possibilities

1. [Communication Mode] Live for face-to-face interaction.
2. [Interaction Types (Traditional)] Learner–Teacher, Learner–Content, Teacher–Content.
3. [Interaction Types (IoITE)] Learner–Sensory-of-Things, Learner–Effectors-of-Things, Learner–AI-Environment, Teacher–Effectors-of-Things.
4. [Interaction Context] N/A.
5. [Content Type] Active.
6. [Content Creation] Socialisation and internationalization.
7. [Content Form] Tacit.
8. [SoT] Attendance and emotional recognition.
9. [EoT] Proximity, Emotional and learning states.
10. [eTools (IT-Mediated)] Peer-to-peer collaboration and competition.
11. [eTools (Intelligent)] Simulation, competition, automated assessment, and gaming.
12. [Levels of Intelligence (~data)] Collection.
13. [Levels of Intelligence (~System)] Platform.
14. [Levels of Intelligence (~Network)] Local.
15. [Pedagogy] Cognitivism, behaviorism, and constructivism.
16. [Teaching and Learning Forms] Coaching, Mentoring.

Requirements...

Classroom management entails a lecture plan, students learning activities and engagement, learner–teacher, learner–content, and teacher–content interactions, classroom physical environment management such as climate conditions and seating, attention, and students' psychological and behavioral states. Having an active classroom (versus a passive one where the professor is only lecturing) is key to classroom management, where tacit (from professors' real-life experiences to students) knowledge is processed via mechanisms of socialization and internalization [49]. Data regarding students' emotional state, emotional recognition, and learning state can be captured by sensors and effectors of things for purposes of enhanced engagement and student cognitive flow to navigate around boredom and apathy. Intelligence at the data and edge levels can be executed to facilitate the interpretation of this data. Activities for learning can then be devised based on possible pedagogies anchored in cognitivism, behaviorism, and constructivism. The classroom can, therefore, be utilized to provide coaching and mentoring by the professor, teaching assistant (TA), or invited speakers from industry through the animation of such activities as case studies.

Design/configuration

In the classroom management context, design configuration entails three key dimensions: Physical space, pedagogy, and etools to be used, including AI and 'things'. As far as physical space management, once the number of students registered to a course is known, an AI can be utilized to find the appropriate classroom based on criteria of number of seats and student proximity requirements (considering, for example, the case of a COVID-19 policy). The AI can utilize data from student surveys about the classroom environment, historical data captured from student's wearable sensors (mobile phone or smartwatches), videos from previous lectures in the same classroom, orientation of windows with respect to the position of the sun, classroom temperature patterns, and efficiency of climate control, to assess the optimal conform level for the number of students to be placed in a specific class. Moreover, the AI responsible for classroom usage optimization can combine the above information to ensure not only that overall facilities are utilized optimally [30] but also integrate in its optimization algorithm the environmental conditions and requirements of the classroom to ensure an optimal learning environment as well.

At this point, different intelligences can be utilized at the data, system, and network levels, depending on their availabilities by the institution and/or third parties. Pedagogy can be designed according to the professor's learning outcomes and may include activities based on different learning theories (item 15 from Table 7). Similarly, for assessment methods, various etools, including AI, such as peer-to-peer learning, collaborative projects, intelligent adaptive systems, and gaming, can be used to facilitate attaining the determined learning outcomes. The designed pedagogy is then operationalized and configured via a set of activities.

Learning activities

Learning activities, individually or combined, constitute a pedagogy that can be participatory, collaborative, competitive, automated, adaptive, coached/mentored, simulated, augmented, or game-based. On the one hand, these activities can be fully intelligent with the support of software agents that can be configured with supervised or non-supervised (among other possible methods) artificial intelligence. On the other hand, the activities can be hybrid with human intervention (supervised or unsupervised). Moreover, their level of intelligence can vary from simple rules of thumb to deep machine learning.

Peer-to-Peer (P2P) learning has been gaining attention over the past decade and presents very interesting and effective learning opportunities. In this case and based on some of the author's innovative P2P experiences over the past two decades, P2P sensors, effectors, automation, and AI, have jointly shown to support and facilitate learning via knowledge generation, reflective practices, peer and self-assessment, and overall knowledge management.

A use case describing what has been partially implemented via an automated process integrated as a learning tool within a digital learning platform begins with the instantiation and configuration of a P2P learning activity session. Control parameters include the subject area, duration of each of three phases, synchronous or asynchronous, type of questions to be generated by students, number of questions to be generated for each type, and levels of difficulty for questions to be generated. Other AI parameters can be specified, such as similarity between two questions generated by two different students and alerting students by presenting a similarity index.

In phase 1, students are asked to generate a few questions of different types and levels of difficulty. The AI would guide them through the requirements. The student would evaluate every one of their questions across several variables, such as relevance and level of difficulty. Students can also upload resources (documents, links to websites, videos, etc.) to provide references for the questions they generated. Once all the students have entered all their questions and answer keys, phase 1 is closed and phase 2 is opened (students are alerted). Phase 2 engages students in evaluating their peer's questions. Based on the professor's requirement for the number of evaluations per question, the AI would assign questions across students so that the number of required assessments for each question is met and such that students would not get their own questions to evaluate. Each student is provided with the average (and other statistics) of their peer's assessment of their questions.

In phase 3, an AI would generate an exam from the pool of student-generated questions based on a high level of clarity and relevance of the questions. One or more exams can be generated to serve different goals. An exam can be generated based on student profile information or survey data taken prior to the P2P activity. For example, an exam can be generated using male students, and only female students are assigned to take and vice versa.

It is also worthwhile noting that in this case, if we consider a class of 100 students and each student is asked to create five questions and upload three resources, the digital classroom will create from one P2P session knowledge assets of 500 questions and 300 resources. Using AI to filter and categorize those resources, these data and objects can be used for many purposes to support student learning.

5.1.2. Use Case 2—Brief Example: Proctoring Exam

Higher education institutions today are continuously increasing the number of students per class (up to 350 students per semester per class) and more so in online classes (over 2000 students per semester per class). Moreover, in the case of online classes, students can be located around the world in different time zones. For scoping purposes, considering the situation where students must present themselves physically for the final exam, challenges in this case include the authentication of a student's identity. The only possible authentication can occur during the final exam, where the student physically must present him/herself and complete the exam in a supervised environment in a smart computer lab, that controls internet access and the classroom environment.

As such, this use case scenario pertains to solving challenges associated with environmental management, student flow, student authentication, versioning of exams, access to the digital platform, processes to eliminate cheating, intelligence support at all levels from network to assessment, maximization use of computers, optimization of students flow via smart scheduling and real-time alerts/notification considering that students may finish the exam earlier than the allotted time, and management of students with disabilities and/or learning difficulties.

In this case, the exam is to take place in a computer lab. A student registers for a day and time from the posted schedule and is then assigned a computer, which they will use to complete the exam. The student specifies their flexibility of the time that they have chosen, and based on that, the AI will notify the student to present themselves to the TA when a computer becomes available. Initially, the first student group of the day will arrive at the same time. Subsequently, a student will be notified in real-time of the availability of a computer, considering classroom environmental conditions such as temperature and their proximity. If the student says yes, then he/she will be provided with instructions on the computer assigned to them and can proceed to the examination room, otherwise, another student will be notified, keeping computer usage at its optimum. Once the student is authenticated via any number of methods, such as thumbprint scan, or facial recognition, the student is allowed to login to the platform and request his/her own personalized exam.

Once they log in to the system, the exam will then be generated on-the-fly, managed, and pre-configured to ensure equality among all generated exams, across the following parameters: level of difficulty, mix of different types of questions such as multiple choice, true or false, and short answer questions, covers all learning goals as per professor's setup, and no two exams should have more than, for example, 20% of questions in common. In addition, the exam configurator should have certain preferences, such as the ability to control the maximum number of any type of question, manage in real-time the difficulty level of questions and reassign their difficulty value, use AI methods, such as fuzzy logic, switch on student assessment of each question on its relevance and quality, as well as provide feedback on any question or exam. When the exam is completed, all questions can be automatically corrected via a supervised AI, and students should be able to see their final exam results after the last student has completed the exam or as configured by the professor. Using AI, students can also request a report on their exam performance explaining their mistakes and the scores.

5.2. Use Case Scenario 2: Learning

5.2.1. Use Case 3—Detailed: Game-Based Learning—Engagement

This scenario entails the teaching of a game-based pedagogy course on Enterprise Resources Planning (ERP). Students in groups of four compete on running their manufacturing firm for the same market. The game utilizes the real SAP (System Analysis Program Development—Systemanalyse Programmentwicklung) industry standard environment for the management of business processes, including but not limited to marketing, forecasting, inventory management, supplier management, manufacturing design and operation, and analytics. Students play the game in a computer lab where the results of their performance, at the end of every quarter, are projected on the screen showing analytics, which form the basis to discuss (facilitated and mentored by the professor) strategy, tactics, operations, collaboration, and decision-making. The outcome at the end of each quarter is for each group to redesign their strategy for better performance and performance as compared to their competitors (other groups in the class).

Possibilities

1. [Communication Mode] Synchronous (Synch).
2. [Interaction Types (Traditional)] Learner–Teacher, Learner–Content.
3. [Interaction Types (IoITE)] Learner–Sensory-of-Things, Learner–Effectors-of-Things, Learner–AI-Environment, Teacher–Effectors-of-Things.
4. [Interaction Context] N/A. May be inter- or intra-INST depending on the game configuration.
5. [Content Type] Active.
6. [Content Creation] Socialization and internalization.
7. [Content Form] Tacit.
8. [SoT] Emotional recognition and attendance.
9. [EoT] EMO; Learning state.
10. [eTools (IT-Mediated)] Chat, Collaboration, Multimedia, Competition.
11. [eTools (Intelligent)] Simulation, Automation, Gaming, Experience-Oriented.
12. [Levels of Intelligence (~data)] Decision-making.
13. [Levels of Intelligence (~System)] Embedded.
14. [Levels of Intelligence (~Network)] N/A.
15. [Pedagogy] Constructivism, Self-Directed.
16. [Teaching and Learning Forms] Coaching, Mentoring, Experiential.

Requirements

Usually, in game-based learning, a program is specifically designed and implemented to develop certain skills. An example would be an interactive multimedia tool to learn how to design databases using the entity relationship diagram [9]. Another would be the gamification of an industry software standard, SAP, as elaborated above, to learn how to use the software and ERP concepts [50].

In game-based learning, task performance, automation, and engagement are primary. As a learning strategy, this mode of learning would be highly active, experiential, and synchronous, where the learner connects in real-time with the content, the professor, and the teaching assistant. Sensors are used to evaluate engagement since this construct has been shown to be a strong indicator of enjoyment and flow and, at the same time, the state for maximum learning. Capturing emotional recognition, performance, and emotional state would make it possible to measure behavioral and psychological dimensions, including team interaction levels and group dynamics. Using specific AI in the simulation game as well as at the group decision-making levels, would help professors to interpret the learning conditions and provide coaching and mentorship on strategy, operations, and performance.

Design/configuration

In the gaming context, focusing on the state of flow can be one example driving the configuration of the gaming pedagogy. The state of flow is achieved by balancing ability with challenge and is characterized by losing track of time, enjoyment, heightened focus, sense of control, and autotelic. An imbalance between competency and challenge results in stress, fear, being overwhelmed, apathy, and boredom.

In such a scenario, relevant data are captured via sensors, such as wearables, and classroom climate data, such as noise level and temperature, surveys, and performance data to feed into AI that interprets the state of flow conditions as they relate to group work and task performance. Moreover, the AI can prompt group members on issues that require group decisions and alert them to other group members' actions running their firm, such as changes in product pricing and/or investment in manufacturing, to enhance capacity. Professors can then use the AI to make decisions for intervention, such as mentoring and coaching.

From a design perspective, focusing on the state of flow to maximize the learning experience implies the embedding of a strategy that allows students to start with small challenges to meet their lack of skills/abilities to use the SAP software (since it would be the first time they use it) and incrementally increase the challenge via the introduction of new ERP modules or increasing the complexity of the case. To that effect, the design would entail three levels: easy with a limited number of modules, moderate with the introduction of additional modules, and complex such that a new case is reconfigured with access to all integrated modules.

Learning activities

Learning activities associated with a game-based pedagogy would primarily involve the use of software, some guidelines on group work, other tools (applications or web-based), and reflections. In the context of the ERP simulation example elaborated above and the refinement of the design over a period of 3 years (after which the design was frozen as it achieved maximum learning and student satisfaction), the learning activities in specific were:

1. Study market conditions and performance goals and develop a one-year strategy.
2. Group dynamics, roles, and responsibilities. Establish communications standards.
3. Identify variables from the SAP system to capture and enter a decision support algorithm using Microsoft Excel.
4. Run company for one quarter.
5. The professor displays results and ranks the companies' performance, followed by analysis, reflection, and discussion.
6. Reassess strategy and decision-making algorithm.
7. Run two more quarters on the same cycle.
8. Produce a comprehensive annual report including analytics, comparative performance interpretation, and lessons learned.
9. Complete a survey on the state of flow and group dynamics.

5.2.2. Use Case 4—Brief Summary: AI-Assisted Structured Online Group Discussion

Online group discussions are very challenging to integrate in an effective pedagogical framework. This is even more true when classes include hundreds and maybe thousands of students. In some of the authors' experiences, they have taught online classes with over 2000 students per semester. Over the years of experimentation since 2003, we especially tested online forums as a standard tool for discussion of content. The challenges of discussion-integrated pedagogies include configuring forum participation, student timing to participate, quality of student contribution, threading of discussion, integration or implementation of self-assessment, peer assessment and professor assessment methods, managing plagiarism, managing identity, and managing unacceptable content. Considering all those challenges in the pedagogical framework, documentation, and communicating them to the students is a daunting task. In our case, it took several iterations to not only create an effective communication and monitoring strategy but to design a method that can be controlled (and which we had to reprogram by its entirety because a typical discussion forum does not have the required configuration parameters, nor the intelligence requirements).

At first, an open-source web-based forum tool was used, which allowed its configuration by the professor to open any number of forums (based on categories which included chapters and assignments) so students could discuss the content and assignments while the moderator (teaching assistant) and professor could also participate. Certain rules and guidelines were established and communicated to students. In the end, every student who participated (without evaluation of the amount of engagement and contribution quality) would receive full participation points. This was done manually. Over a period of 2 years, as the enrollment increased from the pilot new course from 25 to 700 students, the complexity of managing the forums into some sort of valuable discussion also became proportionally more complex, and a critical point was reached at 250 students, where monitoring, control, engagement, and quality were not manageable anymore. In fact, students started to create threads to complain about assignments and marking, and about the subject matter of the course as being too difficult or irrelevant, despite the rules and guidelines in place.

At this point, we decided to build our own intelligent discussion forum (DF) platform. Many independent DFs can be created for any category of choice. Within any specific DF, one or more discussions can be set up. Students are given instructions on their participation that includes any combination of the following: writing text concerning the instructions of the subject matter (may include a question, a reflection, an analysis, etc., and uploading resources they have used as well to share with classmates) and evaluating posts/discussion of their peers. More specifically, each DF identifies the parameters of engagement that include a minimum number of words for participation and an optimal number of words. Moreover, every student is required to evaluate a specified number of their peer posts by reading through the posts and by selecting the best quality and clarity posts. At the end of the semester, an intelligent algorithm is run, providing a comparative (vis a vis all students' participation) grade of participation based on the above-mentioned parameters. A communication subsystem is integrated to notify students to participate on time.

At this point, this self-contained pedagogical learning activity is pull-based, meaning that students have to log in to participate in the forum (responsive website to work on any device). It can be further improved by integrating AI-enabled IoT to different levels of depth. Sending alerts and notifications to students' smart devices (e.g., smartwatch) when a post is made and allowing them to evaluate it directly via voice or text is one example. Moreover, an AI can be integrated to assess the quality of each post based on historical data and student and professor's feedback, and configuration parameters can be set up for the AI to give opportunity for every student to enhance their post after an initial private AI assessment, thereby enhancing the quality of participation and content generated. Recall, if we consider a class of 1000 students and there are 10 discussion topics, then 10,000 posts are generated in one semester. The data can be significant enough to allow AI to improve over a short period of time. Other methods of intelligence can be integrated that utilize different environmental and geographical variables (sensors) to further enhance the intelligence of this learning tool.

6. Challenges and Discussion

6.1. Realizing the IoT

With an expected number of connected devices to exceed one trillion by 2025 [51], ultimately, the IoT global ecosystem aims to be unified, streamlined, effortless, and universal. In the higher education sector, it is important to achieve an agreed-upon global set of standards by which the IoT promise for pervasive integration can be realized. This is critical for the global education sustainable development goal of the United Nations. These standards, which ought to consider the immersion of intelligence in the IoT educational ecosystem need to be reconciled across different educational systems and countries to allow for large-scale deployment. Only then can the IoITE be realized at the global level and reach its full potential of personalization across age, culture, gender, and background. The use of artificial intelligence will ensure that every individual across the world can get an equitable, fair, and customized learning experience. Today, however, there are a few challenges that need to be resolved at the educational system level while at the same time contributing towards a sustainable advanced fair education (SAFE).

The IoT is a relatively new paradigm. Advances in technology innovations are outpacing their application and use. This is leaving organizations and end-users scrambling to adopt and adapt. Moreover, researchers continue to struggle to keep up with investigating, testing, and understanding the impact of those advances on stakeholders. Furthermore, IoT advances are becoming ever closer to society in all respects, blurring all boundaries for clear analysis of interactions and increasing the multi-disciplinary nature of its application and use. This is evident in the emerging research area of edge computing [8].

Unchanged since it was reported in 2012, the IoT ecosystem (which has evolved into increasing levels of complexity) still lacks any theoretical development, despite the publication of some standards for practice, as well as a unified and harmonized technology architecture that allows for seamless immersion of both virtual and physical worlds [52–54]. These key challenges that are directly related to IoT in general, and as a result, impact IoITE, are well elaborated in [53], which we briefly identify herein:

1. The diversity, scale, and complexity of different technologies need to be interconnected in an intelligent way via sensors, such as cameras, biometrics, physical, and chemical, which also need to be nonintrusive, transparent, and invisible. These technologies need to resolve issues of compatibility, deployment, cost-benefit, dependencies, and management thereof, which entail some of the more important barriers to the application of IoT by different stakeholders.
2. Investment and adoption of necessary and appropriate hardware with embedded intelligence for the smart management of power usage, bandwidth, various systems, and services.
3. Privacy and security have been and remain at the top of the agenda for the IoT and all its applications. Important challenges include the adaptability and suitability of security architecture to different applications. 'One model fits all' is not efficient and may even lack effectiveness.
4. Refs. [20,21], a United Nations agency, has worked on standards for the IoT. However, more efforts need to be made for the continuous development and coordination of standards to include all stakeholders from industry, research, and governments at a global level.
5. In the e-commerce arena, contrary to mature applications, the IoT is riddled with possibilities (see Table 6 in the context of education), uncertainties, and inequities. This makes business models much more complex to devise and subsequently, makes technical requirements more challenging to specify and implement.
6. Sustainability of IoT, although feasible for small applications, is much more difficult to manage and much more costly for the larger enterprise. IoT must be part of the organization's digital strategy plan where the traditional IT department would need to be redesigned into the IoT department. Some barriers, such as traditional outsourcing models, need to be reconsidered and their business model redesigned to achieve IoT agility within the organization.

6.2. Barriers to IoIT in Education

It is clear from the above that the fundamental elements of the IoT ecosystem are in its evolutionary stage and touch all industries. Considering the education sector alone, in addition to the general IoT challenges, there are specific barriers and difficulties that we highlight.

1. Academic institutions usually have an IT department to deal with software and hardware infrastructures. The department is far removed from the business of education, and, therefore, their support for teachers and students does not exist when it comes to using technology for teaching and learning. This is still true even though many academic institutions establish instructional technology units to bridge this gap. Unfortunately, instructional technology specialists lack depth of knowledge in IT and, more specifically, in IoT. This challenge can only be addressed via continuous IoT professional development training at the edge of teaching and learning, namely for professors and teaching assistants.
2. Academic administration tends to regulate the use of IT (and, by extension, IoT) and its use in the learning environment, thereby limiting any type of teaching and learning innovation. This begs the question of the extent of academic freedom in the attempt to innovate in teaching, learning, and education research. Academic freedom to the extent of IoT use has not been addressed. Fear of repercussions remains and, as such, IoT application is suppressed.
3. The connection via devices between behavioral, physiological [31,55,56], and administrative functions is a major challenge for higher education academic institutions. This is primarily due to the lack of understanding of the benefits, which include management of people flow, classroom utilization, energy, attendance, physical and psychological wellness, registration, and learning characteristics, such as attention.

Learning in the era of IoT and artificial intelligence changes the rules of the playing field for what professors can do, what students can experience, and what administrators can tolerate. Imagination is the limit, as the combination of different parameters identified in Table 7 can produce different experiences, outputs, and outcomes. Learning innovation inspired by the IoIT and potential opportunities of intrinsic exploitations, interconnection and improvement is challenging the foundations of education, causing significant institutional cognitive dissonance, and proving difficult to navigate. The notion of 'paradigm' is no longer applicable to learning as a fixed method but signifies the open opportunities for creating different pathways leveraging the IoIT to expand the learner's horizons, skills, capabilities, and thought in directions and areas that were not possible before. These pathways include notions of learning, such as social, hybrid, flipped, blended, mentored, case-based, experiential, interactive, immersive, adaptive, self-directed, personalized, customized, and continuous [57]. Many more can also be devised.

6.3. Emerging Artificial Intelligence and Promise for the Education Landscape

The IoT as only 'things', has been limited in terms of its capabilities with the notion of intelligence, until the recent paradigm of edge computing. However, intelligence as a concept is rather complex, with many facets and degrees. So far, we have proposed an Internet of Intelligence of Things schema and a conceptual model as it applies to higher education. We are still scratching the surface in terms of putting it all together and need many more studies to analyze and reveal ways to produce a wholistic and seamless IoIT ecosystem, specifically for the education sector, especially when we consider the integration of new infrastructures based on innovations, such as blockchain. We believe that the key player for future research in this endeavor is in the innovation, automation [1], and development of the intelligence ecosystem and its applicability at the 'edge'. We briefly introduce three novel advances in intelligence approaches that show promise: Internet of Agents, ambient intelligence, and experience-oriented intelligence.

A novel Internet of Agents (IoA) approach to the intelligence integration of IoT was demonstrated by [4]. The purpose of the IoA is to add and enhance the autonomous and intelligent functions of IoT artifacts, namely EoT, SoT, and platforms. In essence, IoA has been framed as the integration of software into the IoT, such as smart objects like smart TVs, smart fridges, and smartwatches. Integrating software agents into the IoT can be evolutionary where the process of the IoT necessitates the engagement of the end-user to adapt to the IoT network behavior or software agents are embedded in IoT ecosystem to manage associated resources and objects. The IoA can be applied in education at all levels, from classroom management, teaching and learning to campus facilities and resources management: smart classroom, smart campus safety, smart buildings, smart grids, smart mobility, smart certification.

As technology-enabled capabilities increase in intelligence via approaches, such as the IoAs, the gap between IoT physical ecosystem and the environment becomes closer, with increasing perceptiveness and responsiveness to people's presence, hence, the term ambient intelligence (AmI) [56]. AmI can be considered a revolution in the emerging IoT paradigm, which entails intelligent sensing and adaptability [57]. The vision of AmI goes back to the 1990 European Commission's Information Society and Technology Advisory Group (ISTAG), where they proposed the notion of digital environments that are integrated with sensors, effectors, and intelligent systems [58]. With this AmI notion, awareness, recognition, and adaptation become the key operative concepts to operationalizing artificial intelligence towards the purpose of enhancing individuals' experiences.

More to the context of this study, Ref. [59] introduced an ambient intelligence-based classroom model that aims to capture data that may be used to assess student fatigue based on previous day activities. Ultimately, the goal is to develop a personalized learning strategy. Other more recent studies on AmI include the following: investigating human action recognition for autonomous systems [60], identification of pathways towards the realization of AmI utilizing task-oriented sensing at the edge of computing [61], language learning [62], and the metaverse [63]. However, research studies in the area of education are lacking.

The AmI proposition is to integrate new types of IoT capabilities. Users are assisted by IoAs in their everyday activities, while the AmI gains increasing levels of knowledge about them. Consequently, the environment by being pervasive and non-invasive, will at the same time avoid threat to safety, security, and privacy. AmI today is at the point of providing personalized and tailored user-centered capabilities to meet their preferences and needs. Advances include the use of machine learning to increase the level of autonomic environments, with learning capabilities and efficient adaptability.

As much excitement as there can be about the IoT's capacity to generate data and information, the question of how to extract quality information from the data produced and how to facilitate the sharing of resulting knowledge among the different IoT networks within its ecosystem remains to be answered. Ref. [54] propose the experience-oriented smart things (EOST). The EOST performs two functions, namely utilizing deep learning elaborated by knowledge representations to manage knowledge processes (acquisition, representation, and storage) and finding ways to share the knowledge necessary for decision-making support.

6.4. Digital Transformation Capabilities and Limitations

Ref. [1] provides an overview of digital transformation (DT) and proposed definitions by different researchers. A consensus on the definition of DT is not evident yet. However, Refs. [64–66] provide representative characteristics of what DT may entail. They elaborate that DT is multidimensional, which involves the integration of digital technologies (in our case, IoT and artificial intelligence, and in a more general sense, robotics, augmented reality, 3D printing, and other technology solutions to Industry 4.0) into organization's operations requiring them to consolidate their business and management model, thereby necessitating the continuous improvement (adaptation) of competencies and capabilities at all levels. Ultimately, this continuous change is to ensure a sustainable value proposition to customers while maintaining business well-being and growth.

Engaging in digital transformation, higher education institutions must change across three development areas, namely that of the institutional strategy, educators, and learners [65]. The impact of DT runs deeper than just technology integration and necessitates a change in organizational culture and employee capabilities, which are dependent on the organization's digital maturity level [67]. Ref. [64] identifies two stages to DT. The first involves digital infrastructures, systems, and platforms, while the second is centered around the exploitation of the digital infrastructure, digital systems, and platforms. In general, the notion of digital transformation is perceived to be disruptive and caused by digital innovations, such as IoT, artificial intelligence, and virtual and augmented reality. However, the first phase, which is digitalization, entails end-user and organization's adoption of digital innovations, while DT can be viewed as ambidextrous (explore and exploit) activities as part of a digital strategy [66].

The body of knowledge identifying challenges and limitations to the implementation of DT is dispersed and specific to the context. Two studies demonstrate the scope of these challenges where the first, Ref. [66] shows how the t-shaped model of a viable systems approach (horizontal) and competencies-capabilities dichotomy (vertical) can be utilized to address challenges of DT in organizations, and the second [64] studies the digital transformation process in Vietnamese higher education. We stress that the implementation of IoITE in higher education for education management and learning cannot be realized without a DT road map. Therefore, another set of challenges to consider includes those related to DT.

A road map to DT requires that all stakeholders (management, administration, all functional units, educators, and students) engage in the process. Synchronizing all stakeholders to the same road map makes the goal at hand multidimensional. We agree with both [64,66] that capacity and capabilities are two of the most important challenges, especially for low-income, under-developed, and developing (to different extents) countries. More importantly, it is a country's agility to adapt its capacity and capabilities to the ever-changing terrain of digital innovations and transformation. In essence, in addition to those mentioned above, these challenges require that stakeholders (primarily human resources) learn (and upgrade their capacity) about the paths to support DT, which can be mapped across six levels: Evaluate, synthesize, analyze, apply, comprehend, and know. Other challenges include areas related to the legality of digital innovation use, governance, best practices, and regulations. In the case of low-income countries, investment in DT costs can make it very difficult to achieve success.

6.5. The New Paradigm of Learning Analytics

The most recent advancement in the application of information technology in education is learning analytics (LA), which followed learning management systems (LMS) and social networks (SN). LA can be defined as the capturing of relevant data to maximize the learning ecosystem. Ref. [68] provide a review of how LA started by proposing frameworks that are generic as well as specific which relate to such areas as data protection, personalized learning, and student retention.

LA has been applied and utilized in laboratory-based disciplines (natural sciences, biology, and chemistry) [69], and professors have implemented it in diverse settings (primarily technical), such as the prediction of underachieving students, automated feedback, development of strategies for optimal learning, pedagogical support, trustworthy peer assessment [70], and facilitating effective teamwork and collaboration [71–74]. The integration of AI with LA opens a wide range of educational opportunities supporting the personalization of learning, adaptive designs for instructions, and learning-process-orientation optimization [75–78].

Considering the current state of AI-integrated LA, where the scope of publications is limited to the optimization of AI algorithms, few studies have investigated the impact of AI models on teachers' practice [75], and research on the use of AI to support pedagogy is scarce and descriptive. Therefore, AI-integrated LA adopts a strategy heavily committed to the capturing of educational data and the development of algorithms and methods to ultimately enhance, optimize, and maximize the teaching and learning experiences of teachers and students, respectively.

7. Conclusions

IoITE builds on the concept of AIoT as a novel paradigm that proposes the use of intelligence in the various layers of the IoT as an integral architectural component of the educational institution's global ecosystem, intra- and inter-institutional (including learning). The SLR findings in this study confirm those from other studies [79–82] that research on the Internet of Intelligence of Things in higher education context continues to be scarce and limited. Consequently, we proposed an IoIT conceptual model in the higher-education context. We then conducted a survey and presented the results of the pilot survey study, which includes questions that can provide us with insights into professors' use and knowledge of the IoT and integrated intelligence. It is worth noting that in our literature review, we did not find any studies that attempted to obtain feedback from educators on their knowledge or perceptions, use, and readiness to use IoT in their profession. We finally mapped the elements of the conceptual model into a morphological net, which was then elaborated on and discussed via four use cases to demonstrate how our model can be applied in higher education.

Based on the pilot survey results, it seems that, in general, educators (especially in non-technical disciplines) have an idea about what the IoT is and limited use of IoT tools, making their capacity to explore and exploit IoT teaching and learning opportunities limited. Even in technical areas, professors tend to know, at a more detailed level, what is entailed in the IoT, but their use of it is highly specific and technical, focusing on a highly specialized, which is a non-transferable learning activity, such as a simulation of a process. To that effect, the IoITE paradigm and its application still have a long way to go and need much more theoretical and applied exploratory research before it can be fully exploited and operationalized by higher-education institutions, especially in areas of study other than engineering.

We note that the extraction of information from associated data-generating sources of 'things' occurs increasingly closer to the edge of the IoT user ecosystem, which is the emerging and surging computational paradigm of edge computing [8]. Our exploratory study shows that at the computing edge, professors have reported hardly using IoT and artificial intelligence in their personal lives. With large amounts of data being generated via mobile devices, wearables, cameras, and other 'things', "Artificial intelligence on the edge" has become a critical space for the integration of intelligence into smart universities. As such, the three different types of intelligence identified above provide rich opportunities for integration at the IoT network edge [83–86].

However, these opportunities can only be realized when higher-education institutions make a tangible and sustainable commitment to what our SLR results, exploratory survey outcomes, and conceptual models demonstrate. In that respect, our study is relevant via its implications to practitioners as follows:

1. The need for institutions to have an integrated educational intelligence architecture (Figure 3) for their administrative and management functions (including classroom management). This implies the commitment and effective alignment of digital structures, data strategy, learning strategy, and digital platforms and services into the overarching institutional digital strategy.
2. Consequently, the operationalizing of teaching and learning intelligence mechanisms can be realized via the configuration of the IoT and AI in the learning process by professors. With the alignment (Figure 3), this configuration can take place at the data, information, knowledge, and intelligence layers of the learning process. Therefore, every layer would have targeted intelligence serving the learning process, from comfortable learning spaces to innovative and customized/personalized pedagogies.

3. However, today, our exploratory survey shows that, in general, professors in higher education have limited use of IoIT in their own personal lives, and only a few have used it in their practice of teaching and learning. These findings have important implications for institutions, such that they need to have sustainable mechanisms for the continuous professional development of educators with regard to IoT and AI, as well as policies that encourage them to use IoT and AI tools via financial and service support while advising and protecting them from potential backlash and other serious or benign liabilities. Today's institutional strategies do not seem to take People-of-Things into consideration.
4. From a learning integration perspective, it would be logical to say that for professors to have the capabilities to use IoT in their practice, then, they would need to have a good knowledge of the IoT and AI concepts. Our exploratory study shows that around two-thirds of the professors reported to have little or no knowledge of sensors and effectors, which are the most critical element in the implementation of IoT in any context. Our study results, therefore, advocate for education regarding IoT sensors and effectors to all professors and potential uses in their practice.
5. The top five uses of information technologies that were reported by surveyed professors include learning management systems, messaging, streaming videos, video conferencing, digital books, and smartphones, all of which are not necessarily IoT tools but simply indicative of the extent at which professors have used digital tools in their classroom. When asked about their use of smart apps or sensors/effectors of things, such as smart apps, artificial intelligence tools for learning, smart tutoring, and gaming, only a few reported having used them. Our study results, therefore, advocate for the need to facilitate the support of sensors and effectors in an attempt to encourage their use by professors in their practice.
6. Overall, institutions
    a. can use our conceptual model of IoITE in the development of their digital strategy, assess the extent of their capabilities to currently use IoIT in their learning processes, and develop a strategy for its implementation aligned with its strategic directions, and
    b. can reproduce the survey to assess the level of readiness of their professors in using IoIT in their classrooms for teaching and learning. The results can help management in establishing action plans to meet the institution's strategic planning.

As we embark on this study to understand better the integration of intelligence in the IoT and in the higher education sector, more specifically in the learning environment, we acknowledge some limitations or opportunities for future research. Granted that literature in the technical areas of IoT was outside the scope of this research, we believe that there are case studies on the building of specific IoT applications as demonstrated in classroom setups. Expanding or conducting an SLR on IoT applications in education case studies alone may provide another set of insights for factors of success and/or failure of their implementation.

Moreover, the survey we performed entailed only 28 participants, as it was intended to obtain feedback from various universities around the world and not to assess any specific institution. This gives us an overall idea of global general practices. Our survey would need to be reproduced with a much larger sample to not only obtain more generalizable data but to perform statistically significant factor and causal analyses. Furthermore, the questions can be refined in terms of the extent of understanding and use of IoT and AI, as well as required conditions for implementation in learning.

The survey can be further expanded and modified to study the responses from students in terms of their readiness, willingness, and comfort levels to use IoIT in their learning environment, especially since to do so, data about student behavior would be required. Future research on university professors' beliefs and use utilizing the technology acceptance model (TAM) and/or the unified theory of acceptance and use of technology (UTAUT) can provide further insights on how to implement IoIT in their learning practice.

As far as empirical studies are concerned, we hope that this research will provide the motivation for other researchers to aim for the development of an IoITE model equivalent to the classical technology acceptance model and its derivatives. Many classical constructs may not apply today in the IoT context, as questions such as perceived ease of use, usefulness, and intentions, have lost relevance, and more important constructs, such as those related to cognition and emotions, are timely.

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Abbreviations

Abbreviations	**Description**
ABS	Abstract Search
AIoT	Artificial Intelligence of Things
AI	Artificial Intelligence
ALL	Search in all fields
AmI	Ambient Intelligence
ASYNC	Asynchronous
BD	Big Data
DT	Digital Transformation
EOST	Experience-Oriented Smart Things
EoT	Effectors of Things
ER	Emotional Recognition
ERP	Enterprise Resources Planning
EXPL	Experiential
INST	Institutional
IoA	Internet of Agents
IoD	Internet of Devices
IoT	Internet of Things
IoIT	Internet of Intelligence of Things
IoITE	Internet of Intelligence of Things in Education
IoPF	Internet of Platforms
IoP	Internet of People
LA	Learning Analytics
ML	Machine Learning
SoT	Sensors of Things
SO	Service-Oriented
TS	Topic Search
TRANS	Transmission
WoS	Web of Science

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