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Analyzing the Users' Acceptance of an IoT Cloud Platform Using the UTAUT/TAM Model

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ABSTRACT The instructional design of meaningful experimental activities completely integrated into on-line Engineering courses is still a significant challenge, by following the sustainable development goal of the United Nations for quality education, the SDG number 4. Remote and virtual laboratories can be a solution to improve this design in distance methodology. This fact has been more noticeable during the COVID-19 pandemic and its consequences with respect to education. Its transparent integration into the learning process and the inclusion of learning analytic features are essential features of these kinds of technologies. Without them, lecturers cannot track the performance and the satisfaction of their students. Our LoT@UNED (Laboratory-of-Things@UNED) platform has been implemented to include all these educational features for IoT environments, ranging from edge to cloud computing. Taking the advantages of the IoT paradigm, this platform involves acquiring practical competences within IoT and edge-cloud programming topics, among others. Furthermore, its flexibility allows us to host other areas, such as cybersecurity. Specifically, our platform incorporates a set of sustainable capabilities (scalability, availability, and security), so contributing to the SDG 4 challenge with a low-complex and efficient solution for quality distance education. To analyze the impact of our proposed solution, this work also focuses on studying the influence among several acceptance UTAUT/TAM factors during the students' learning and teaching process. To achieve this goal, both exploratory and confirmatory analyses have been conducted. The reliability and validity of data are also analyzed. An improved structural equation model has also been studied, satisfying several statistical indicators according to the recommended thresholds in the current literature. The usefulness of our platform, easing the users' attitude and having a high availability of resources affect positively the intention of use our IoT cloud solution and, as a consequence, the great quality of the education process.

INDEX TERMS Cloud computing, distance education, sustainable development goals (SDGs), evaluation, IoT learning environments, SEM, UTAUT/TAM models.

I. INTRODUCTION

The achievement of high quality of education, enhanced with modern technologies, can promote developing a better digital society. Moreover, the generated new knowledge in people enrolled into official regulated learning processes and vocal

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education and training will also contribute to the growth of the economy and employment of society. According to these principles, our work is mainly aligned with several Sustainable Development Goals (SDGs), as the SDG 4 for quality education is [1].

Internet revolution in combination with emerging technologies for different purposes is transforming our daily life. This network can be seen as a global network with plenty of

devices communicated among them to perform some actions. These nodes interact across heterogeneous hardware and software platforms by including dedicated and embedded devices [2]. This way, it is possible to create scalable network environments flexibly. Physical nodes can be composed of sensors and actuators, managed by one or several control units, whereas software elements define virtualized nodes. Open standards are usually employed in this complex heterogeneous ecosystem, known as the Internet of Things (IoT) [3].

This research topic is becoming a real challenge in many academic and industrial disciplines [4]. For instance, solutions for multiple fields of application are being proposed and experimented, such as e-health for people monitoring [5], customized health-care [6], or biosensors-based environments [7], [8]. Other fields of research are those related to smart cities for traffic control [9], intelligent transport systems for security threats [10], or the vehicle industry [11], [12], among others. Smart agriculture is another growing framework where IoT solutions are developed for efficiency and safety purposes [13]–[15]. Data science can also be involved in IoT environments in this and other contexts [16].

In addition to this, several cloud providers are already supporting IoT integration in the cloud, in order to manage and analyze the generated data, developing and deploying IoT applications for monitoring, visualisation, research, decision-making and real-time action in the cloud [17]. These are known as IoT cloud platforms. A comparative study about these are given in [18], such as IBM Watson IoT, Amazon AWS IoT, Microsoft Azure IoT, or Google Cloud IoT [19].

These modern disruptive technologies will help us to address SDG4 (Quality Education). Since students are not physically present for their learning/teaching process, educators must provide new methods and tools to them during this process. Remote-virtual equipment to facilitate the necessary skills for professional education must be provided and minimise dropouts. This fact has particular relevance in the case of Engineering since practical activities are needed to acquire the required competencies by acquiring a digital culture. This culture will be essential in their future job positions as Engineers to ease society's quality of life and be fundamental for the business development of Industry 4.0. The evident need to improve the quality of online education with modern cloud and IoT technologies is even more obvious with the experienced COVID-19 pandemic.

This way, we propose LoT@UNED (Laboratory-of-Things@UNED), a novel approach since students can perform experiments with real IoT low-cost devices and learn the employment of cloud services simultaneously. Students can also work in several layers from a full-cycle development (edge, fog, cloud). Additionally, the LoT@UNED platform incorporates a set of sustainable capabilities (scalability, availability, security), which are not present in other approaches together. Protocol IoT programming is also feasible with a set of sensors and devices, virtualized devices and Docker-containers. It is also possible to analyze visually

the availability of network resources for quality of service purposes. These features are detailed in the state of the next Section.

Our proposal also considers privacy aspects for the collected data with the GDPR regulation [20] from European Union. The IoT and cloud technologies help us improve the sustainability of the teaching/learning process and promote the quality of education. Students can also work in several layers or levels for a full-cycle development of an IoT solution. LoT@UNED has been incorporated as part of the instructional design of a Cybersecurity subject with a distance methodology.

Secondly, a set of students' acceptance factors (performance expectancy, effort expectancy, attitude, social influence, facilitating conditions and intention to use) are studied. The outcome factor is the intention to use the platform for other contexts. A new Structural Equation Model (SEM) is analyzed and statistically validated using the UTAUT methodology [21], as a core of our proposed SEM models. Before this, an exploratory data analysis has been performed. The reliability and validity of data are also studied. The main novelties of our SEM analyses are the use of UTAUT model with the integration of TAM factors [22], as well as the proposal of a good-fit improved SEM model. UTAUT and TAM, and many of their variations, are well-established models.

Our proposed SEM models are an evolution of UTAUT and TAM approaches by taking advantage of both of them. The main reason for using TAM factors [23] is because of the employment concepts from social psychology. Additionally, UTAUT is a model that incorporates theory for human behavior [24]. An evolved combination of both theories, UTAUT and TAM, is suitable for our purpose of considering technological social psychological aspects. TAM covers the technological point of view and UTAUT the social psychological challenge. Therefore, both are suitable approaches to propose and validate the intentions of individual end-users (in our case, students) to use new technology, such as LoT@UNED. Studies analyzing users' intentions to use IT are actively being conducted with TAM or UTAUT [25]–[29].

This manuscript is organized as follows. Background on previous works existing in the literature is described in Section II. Then, the methodology's details and our initial proposed hypotheses are described in Section III. The LoT@UNED platform is presented in Section IV, and a case of study is described in Section V. Section VI analyzes the obtained results. Finally, some conclusions are provided in Section VII.

II. BACKGROUND

A. VIRTUAL AND REMOTE ENVIRONMENTS

The increasing employment of new technologies could help people in many fields of our society. When it comes to Engineering education, practical learning scenarios become essential to achieve applied skills by spreading critical thinking knowledge. Several previous proposals have appeared in

recent years. Traditional virtual remote laboratories for industrial electronics and solar energy were proposed in [30]–[32]. Additionally, the concept of deconstruction of remote laboratories was introduced in [33]. These remote laboratories were evaluated in [34] to check the quality of online courses in Jordan for renewable energy. As main drawbacks, these proposals are only focused on renewable energy laboratories, as well as they do not cover a full-cycle IoT development neither cloud services.

The experiments are also sometimes taken with simulation as a previous step. In the case of [9], authors use a traffic simulator and a travel/activity pattern simulation for the construction of the scenario. In addition to this, a recent proposal can be found in [35], in which authors proposed an emulated virtual laboratory (based on the EVE-NG technology). This approach is also assessed from the point of view of technology acceptance. They are only ad-hoc specific proposals based on simulation and emulation, respectively, not using real devices. These do not cover all the characteristics of our IoT cloud proposal.

A Crowd-Resourcing Virtual Laboratory (CRVL) is also presented in [36], which is composed of a set of virtual machines. Authors propose a mechanism to integrate a particular virtual machine into their platform by including the integrity testing, configuration, etc. The system uses websockets for the resource communication, and it takes into account fault-tolerance with a secure shell file-system. These proposals employ virtual laboratories, although physical devices are not available for experimentation. In [37], network function virtualization and software-defined networks are also used to adapt remote laboratories to the dynamic users' demands to improve the quality of service of computing resources for smart campuses. It employs virtualization for its purpose.

On the other hand, initial cloud approaches started to be employed for Computer Science Engineering subjects [38], [39]. Distributed computing and cybersecurity approaches have also been a field of study [40], [41], across the way of evolving to an IoT cloud solution. They are ad-hoc proposals for the specific educational context. recent work also studies the acquisition of practical skills and abilities from edge to cloud computing [42] in the field of the IoT cloud paradigm.

As an additional step, this work presents an improved version of the LoT@UNED platform and a case of study with it over a concrete subject, as well as an exhaustive evaluation from the acceptance technology point of view. Our LoT@UNED platform covers a set of features, which previous works do not achieve jointly, as listed below:

- **Functionality (edge, fog, cloud).** Working on several layers from a full-cycle development of an IoT solution is possible in a flexible way with our proposed LoT@UNED platform, ranging from edge to cloud computing. From our knowledge, there are no other IoT cloud platforms for education covering all layers: edge, fog and cloud.

- **Sustainability (scalability, availability, security).** For management purposes at an infrastructure level, a control engine to provide our IoT cloud solution with sustainability capabilities is designed for scalability, availability and security. This design will allow laboratories to support many students with a high quality provided to users and a robust infrastructure. The laboratories' infrastructure is scalable since it is prepared to support a large number of users at the same time. High availability is also an essential capability of our laboratories in terms of fault tolerance management and latency. Securing the infrastructure which supports laboratories is also relevant since the handled data can be critical, and the platform can suffer malicious attacks. As an example, users must only be able to access their related resources with different access levels. These capabilities will make it possible to have a solution with low complexity and efficiency. From our knowledge, there are no other IoT cloud platforms for education covering these sustainable capabilities simultaneously.
- **Practical IoT experimentation.** Students can perform real experiments with real IoT low-cost devices and learn the employment of cloud services simultaneously. Several practical activities are performed and integrated into our solution for the instructional design of online courses. A case of use is given in this work focused on cybersecurity. Other topics can be distributed applications, cloud computing and data science. Vocational education training courses for applied security or cloud technologies can also be considered in the future.
- **Protocol IoT programming.** This feature implies using the hardware sensors and devices, virtualized devices and Docker-container light services at a network level, and programming specific IoT communication protocols, such as MQTT or COAP, among others.
- **Dashboards and Analytic.** It is also possible to analyze the availability of resources to support the dynamic assimilation of topological changes without disturbing the quality of service provided to our users. For example, a performance dashboard shows all the information to detect the saturation of resources; if load-balancing algorithms do not work correctly, the low quality of service or the security level of a group of users is different from the expected one, among other actions.

B. ACCEPTANCE MODELS

The study of users' acceptance of modern technology in different contexts is a hot topic in many applications, such as mobile applications, since they are suitable for rapid communication and dissemination of information through the Internet. In [43], authors have studied the acceptance of this type of technology in contact with the digital library. A comprehensive study was also conducted in [44] to evaluate attitudes towards the use of an institutional mobile application. The results showed that both the perceived usefulness and ease of use positively influenced the students' attitudes.

Nevertheless, few efforts have been done to analyze the variables influencing chat-bot employment in terms of performance, effort and habits [45].

From the point of view of security in cloud systems, some efforts have also performed. In [46], a hybrid two-stage is proposed and analyzed; with 1) a structural equation modeling, and 2) an artificial neural network model; in order to predict motivators affecting the employment of cloud services for Indian private organizations. In particular, the Technology Organization Environment Model (TOE) is extended with security risks, when employing a cloud technology for the first time.

In addition to this, it is needed to identify the critical success criteria in order to examine structure, reliability and validity of the criteria in the Small and Medium Enterprises (SMEs) industry, some of them are specific of the cloud computing approach [47]. These factors can help organizations with their investments in cloud technology. The identification of critical success factors for the adoption of cloud technologies for business performance through the integration of analytical hierarchical processes and structural mediation models, in terms of trust and perceived security risk, may also become very relevant [48]. These both factors do not have any mediation effect on business performance.

For distance education, it is also quite relevant to study the students' acceptance of a new technology to decide the intention of use it [49], which is integrated into the instructional design of a subject [50]. The Technology Acceptance Model (TAM) [22], [23], as well as a great variety of adaptations and extensions, have been proposed for this purpose. A recent work [51] proposed a structural model based on TAM to explore the acceptance within online learning platforms with virtual laboratories. Additionally, some modifications of TAM have been proposed in order to measure the quality of on-line courses [34], [52]. Another extension of TAM [53] pays attention to the social media influence over the students' satisfaction and their academic performance. The Task-Technology Fit (TTF) theory is used for the improved model [54].

On the other hand, carrying out proposals that extend the original TAM model to study the satisfaction of a technology within e-learning is not a new line of research. Indeed, it has been done for many years, depending on the specific characteristics of the context where learning is being analyzed. In [26], a comprehensive review of these types of TAM models was presented. The core variables used in TAM are the perceived usefulness of a technology, its perceived ease of use, attitude towards using it, and the behavioral intention to use it for further purposes. This last characteristic would imply a high quality of the system. All of them have been included in our study, as detailed below.

Another approach is UTAUT (Unified Theory of Acceptance and Use of Technology) [21]. UTAUT is considered very efficient and has higher explanatory power than other models [55]. Most researchers have used UTAUT to test new technologies with the expected performance and effort as

key factors [21]. These both factors correspond to perceived usefulness and ease of use with the TAM theory, respectively. In this sense, the UTAUT methodology is used in [24], in conjunction with traditional TAM factors, to analyse factors that influence users' intentions to employ particular mobile electronic health record systems. Some previous works have already proposed combined extensions for specific learning purposes, such as rural students' acceptance [56] or the students' acceptance of remote-virtual laboratories [35], [57]. UTAUT has also been applied for the students' acceptance when mobile learning is employed [27].

In our particular case, the influence of several acceptance factors during students' learning/teaching process in the cybersecurity context is analyzed. TAM factors are used due to our interest in social psychology concepts [23]. The UTAUT structure with the integration of TAM factors in the model is employed as a starting point since it includes theory for human behavior [24], which analyzes both theories at the same time.

These factors are: i) performance expectancy (perceived usefulness in TAM); ii) effort expectancy (perceived ease of use in TAM); iii) attitude toward the technology; iv) social influence; v) facilitating conditions, and vi) intention of use. A structured experimental method has to be studied with UTAUT/TAM, improved according to our findings for the case of LoT@UNED, and validated from the point of view of both exploratory and confirmatory ways. This way, we will be able to study the intention to use the proposed technology of students.

A first UTAUT model approach was given in [58], which is the basis of the current work. The initial hypotheses have now been studied in deep and redefined here since statistical indicators of the confirmatory analysis did not match all the optimal values in ranges of normality. A deep exploratory data analysis has also been performed as a previous step.

From our knowledge, there are not others works in the literature, which proposes and validate new evolved SEM models from an integrated UTAUT/TAM approach. This work will analyze the intention to use IoT cloud technology within an educational context.

III. RESEARCH FRAMEWORK

This section includes both the overview of the methodology used and the initial hypotheses defined in this work.

A. METHODOLOGY

The research methodology of this work, which belongs to the eNMoLab (efficient Network Management of Laboratories) project, is summarised below. Particularly, it is based on the one described in [42]:

- 1) *Technologies to be employed.* A set of IoT architectures, cloud providers, network services, and applications have been carefully studied. In particular, the IBM Watson IoT, Amazon AWS IoT, Microsoft Azure IoT, and Google Cloud IoT have been evaluated. As a result, the proposed LoT@UNED platform employs currently several cloud

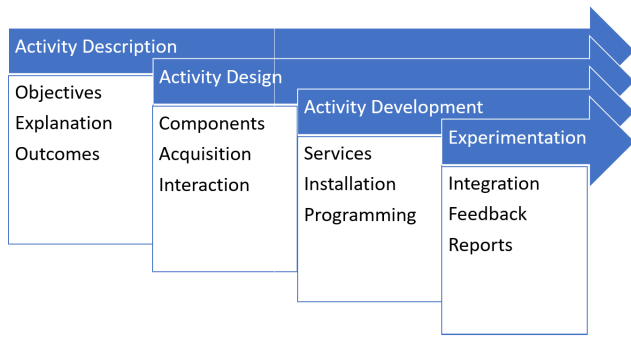


FIGURE 1. Phases of the instructional design of laboratory activities (description, design, development) and experimentation.

services of IBM Watson IoT [59]. Our objective was to study the most disruptive IoT and cloud technologies, which will be able to have a full-cycle functionality (*edge, fog, cloud*).

- 2) *Previous works*. An in-depth literature review has been conducted to study and analyze the existing works related to IoT and Cloud paradigms for several contexts, not only education. Additionally, some works about remote-virtual laboratories and technological acceptance models have also been analyzed. The main databases have been IEEE Xplore, MDPI, and ScienceDirect. We have identified the necessity of proposing an IoT cloud solution for education, ranging from edge to cloud computing, with a set of sustainable capabilities: scalability, availability and security. These capabilities will make it possible to have a solution with low complexity and efficiency. The platform will also allow practical experimentation for any educative context and at network protocol and application levels. No other previous works have been found in the literature will all these features, as detailed in Section II.
- 3) *IoT Cloud Platform*. The LoT@UNED platform has been developed, deployed and integrated in Engineering subjects considering both the IoT and Cloud paradigms. Its architecture comprises three layers: hardware, cloud IoT services, and visualizations. From our knowledge, there are no other IoT cloud platforms for education covering all aforementioned features. The most relevant technical details are given in Section IV.
- 4) *Activities*. A set of practical activities have been performed in LoT@UNED. These have been integrated into our platform and incorporated within the instructional design of online courses. The flow of the design follows the guidelines provided by [60]. Figure 1 depicts all the phases, including the description, design, and development of the laboratory activities:
 - *Description*. In this first phase, all educative objectives are planned, the activity description and outcomes are described.
 - *Design*. The belonging elements for the practical activities are selected, and interaction issues are evaluated.
 - *Development*. Some programming tasks are required, services provisioned, and applications developed.

- *Experimentation*. As observed in Figure 1, this phase is the last within the instructional design, which consists of the integration of the activity in the platform and contents, the feedback provided by the users (performance, satisfaction, etc.), and the generated reports of the platforms (logs, accesses, etc.).

- 5) *Evaluation*. For the evaluation of the technology, the method suggested in [61] is followed, which consist on two main steps, once a set of satisfaction data is collected. These are:

- *Exploratory analysis*. Students' behavior is studied, and the relationship among factors are analyzed. Additionally, the reliability and validity are statistically analyzed. Indeed, validity measures are calculated.
- *Confirmatory analysis*. A set of hypotheses are first defined, studying how physiological factors are linked. Additionally, a structural model is proposed and examined, including a set of goodness fit indexes, which support the reliability of the proposed technology.

B. INITIAL HYPOTHESES

A set of initial hypotheses among UTAUT/TAM factors are defined, analyzed and validated. Before describing these hypotheses, an evolved combination of UTAUT and TAM is presented (see Figure 2). TAM covers the technological point of view of our IoT cloud solution and the UTAUT theory tackles the social psychological impact from our solution. In addition to this, the hypotheses will be reformulated in the second part of the study for proposing a new specific SEM model. This reformulation will be based on the evaluation process, from both the exploratory and confirmatory points of view. A SEM is a causal relational model in which nodes are the factors and links are the defined hypotheses [62], [63].

Each factor can be either manifest or latent variables. The manifest variable corresponds to each question/item of the survey, whilst the latent one is a set of 3 or 4 manifest variables. In this regard, the SEM model can be represented as a graph. This graph's nodes are the factors, and each link is directed by representing a hypothesis. Additionally, each latent variable can be external or endogenous, which are perceived as a variable with a hypothesis.

The employed factors have been designed following the UTAUT/TAM model defined in [24]. In particular, the following ones have been considered:

- *Performance Expectancy (PE)*. This factor is related to the students' perceived usefulness of the LoT@UNED platform in terms of its performance.
- *Effort Expectancy (EE)*. It refers to the students' perceived ease of use of the LoT@UNED platform or the estimated effort to use it.
- *Attitude (A)*. This factor describes the students' resistance and their perceived benefits when using the LoT@UNED platform.
- *Social Influence (SI)*. This factor is the students' perception for collaboration with other students when using the LoT@UNED platform.

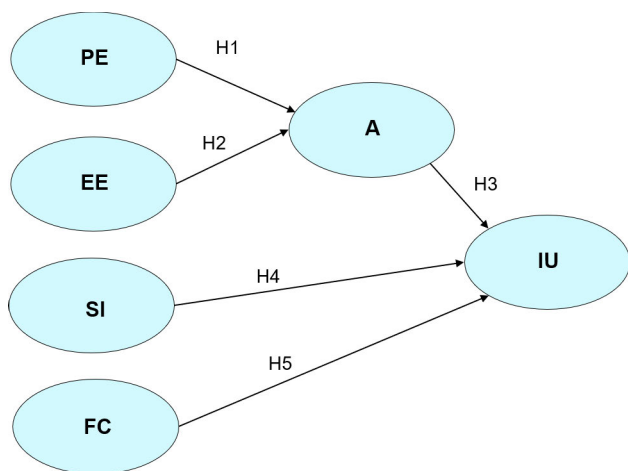


FIGURE 2. UTAUT structure and factors [24]: hypotheses.

- *Facilitating Conditions (FC)*. This factor is the perceived good availability of resources by students. That is, the ease to access.
- *Intention to Use (IU)*. This factor is related to the students' intention of using the LoT@UNED platform in other subjects if it was possible. Consequently, it measures the quality of the provided resources to students in some manner.

Furthermore, the following initial hypotheses have been defined for the SEM model with the UTAUT methodology as a basis (see Figure 2):

- **H1**. The performance expectancy (PE) of the LoT@UNED platform will positively influence the user attitude (A) towards the technology.
- **H2**. The effort expectancy (EE) of the LoT@UNED platform will positively influence the user attitude (A) towards the technology.
- **H3**. The attitude (A) towards the LoT@UNED platform will positively influence the intention to use (IU) the technology.
- **H4**. The social influence (SI) concerning the LoT@UNED platform will positively influence the intention to use (IU) the technology.
- **H5**. The facilitating conditions (FC) of the LoT@UNED platform will positively influence the intention to use (IU) the technology.

IV. THE LoT@UNED PLATFORM

The LoT@UNED platform can be seen as an IoT cloud solution, incorporating several sustainable capabilities (scalability, availability, security), as detailed below. These capabilities allow us to have a very flexible platform to improve the sustainability of the teaching/learning process and promote the quality of education, as stated in SDG4. It also integrates the GDPR European Union Regulation [20] within their workflows. From our knowledge, there are no other proposals, which comprise all these characteristics.

LoT@UNED has been incorporated as part of the instructional design of a cybersecurity subject with a distance methodology. Real IoT low-cost devices and cloud scenarios have been used by students. The portal is hosted in [64]. This platform is composed of two main paradigms, i.e., edge and cloud computing. Some examples of possible functionalities are the employment of cloud services, decision-making or predictions over the generated data by sensors. These are a key part of a cloud layer, but with the need of using complex algorithms.

Figure 3 shows the architecture of the LoT@UNED platform, which is composed of 3 components layers:

- 1) *Layer 1: Edge Paradigm*. The layer is composed of sensors and devices (hardware and software), as well as IoT communication protocols (MQTT, COAP ...).
- 2) *Layer 2: Cloud IoT Service Platform*. It includes a set of IoT services in the cloud, such as data storage, analytic tools, and service APIs. A set of web services with high-computation capabilities are employed.
- 3) *Layer 3: Dashboards and Rules*. It implies decision algorithms, dashboards and software applications.

For the laboratory programming tool, Node-RED is used. Node-RED is a visual development tool for programming IoT cloud environments. LoT@UNED employs the MQTT (Message Queuing Telemetry Transport) protocol for managing the data traffic [42]. It is based on the subscription to one or several topics of the MQTT message system: data, sessions, etc. We can distinguish among two types of interaction mechanisms inside IoT laboratories: acquisition sensors and interaction elements. They determine the following phase, where a software context is created. Thus, this part of IoT laboratory is developed in containers, using Docker technology [65], [66].

Each phase is associated with a specific activity that is deployed in a standard way using Docker containers managed through a cluster manager, based on Kubernetes [67]. The manager provides LoT@UNED with sustainability capabilities for the infrastructure in terms of scalability, availability and security. The platform is prepared to support a large number of users for scalability purposes. It also balances the load of use of different devices to support a high availability of network services. Thus, the use of the devices/sensors is assigned in a dynamic way to the students developing the activities. Our platform is also robust and secure. These capabilities make it possible to have a solution with low complexity and efficiency.

LoT@UNED allows the learning/teaching of the full-cycle development of IoT cloud solutions. Our laboratory is implemented with Raspberry PI devices. Figure 4 depicts the Blade Rack [68] of the LoT@UNED platform. In particular, Figure 4a shows a set of unmounted Raspberry PI devices and Figure 4b the mounted blade rack of the LoT@UNED platform. In addition to this, Figure 5 provides a screenshot of the LoT@UNED platform by examining the state and occupation of the Raspberry PI devices, in order to assign IoT resources for the student's activity. A great variety of sensors and actuators can be added to the platform.

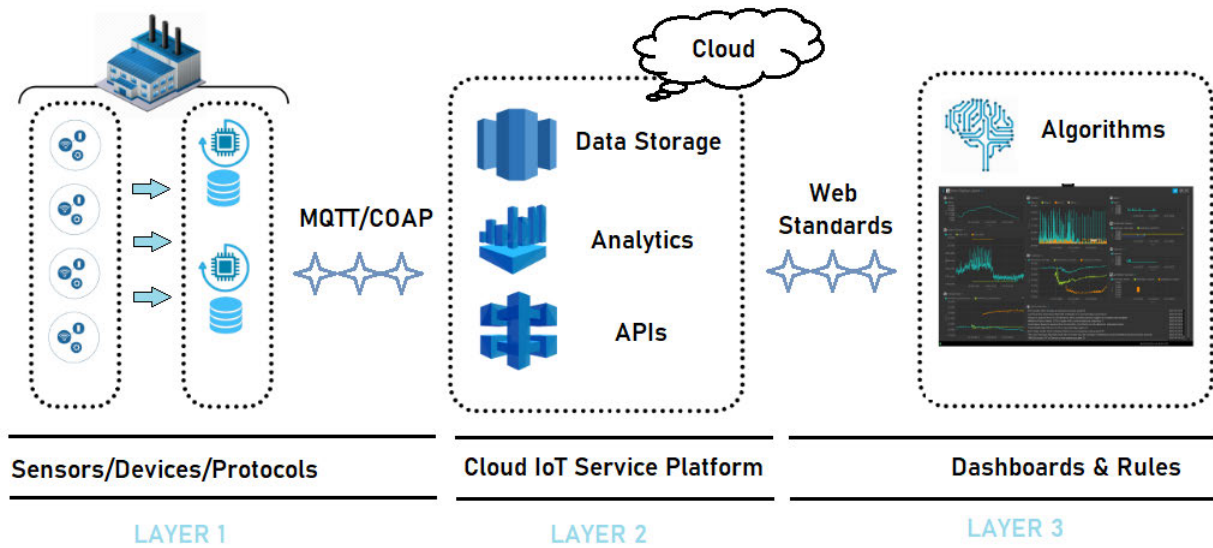
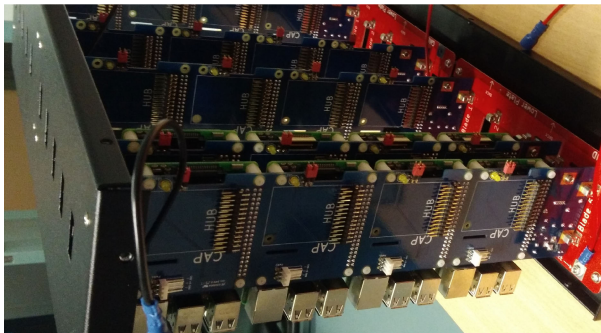


FIGURE 3. IoT solution: infrastructure and components layers.



(a) Devices (unmounted)



(b) Blade rack (mounted)

FIGURE 4. The physical components of the LoT@UNED platform.

Docker containers [65], [66] are used in our IoT cloud solution. Each container, or a set of containers, is assigned to a concrete activity of the student with the needed resources. Docker provides an ideal abstraction layer that is capable of orchestrating containers, seen as light machines, in addition

Home / My practices

Service	Id	Model	Users
testfirewall	b827eb0aac4	Raspberry_Pi_3	0 / 1
testfirewall	b827eb3ce401	Raspberry_Pi_3	0 / 1
testfirewall	b827eb6e5425	Raspberry_Pi_3	1 / 1
testfirewall	b827ebb0e188	Raspberry_Pi_3	1 / 1
testfirewall	b827eb11d7fb	Raspberry_Pi_3	1 / 1



FIGURE 5. Booking Raspberry PI devices for a particular activity in LoT@UNED.

LoT@UNED

Add New Practice

My name:

Id Name Practice:

Practice Name:

Start Date:

Finish Date:

Time to Practice:

PDF:

Service:

Comments:

- Add 1010 info.
- Add 1010 info.
- Add 1010 info.
- Add 1010 info.
- Add 1010 info.
- Add 1010 info.

FIGURE 6. Adding a new activity in LoT@UNED.

to a set of services associated with them. LoT@UNED employs Kubernetes [67] to automatically manage a assignment of resources, load-balance, and so on. It has the capacity of re-configuring devices, when a device fails or a new device is added.

IoT cloud learning scenarios involve the acquisition of transverse competences. Our platform consists of several layers: 1) direct communication with real low-cost IoT component devices; 2) use of communication protocols from the edge to the cloud computing; 3) processing and visualization of the gathered data. The platform has been incorporated into the distance instructional design of a Cybersecurity subject, as detailed next in the study case. As an example, Figure 6 depicts a screen-shot of LoT@UNED, when creating a new activity in the platform.

V. STUDY CASE

The educative context of our research is focused on the subject "Cybersecurity". This subject, which is taught through distance learning methodology, entails 6 ECTS credits within "Computer Science Engineering" degree. It covers network security principles from a practical approach [69]. The teaching/learning methodology supports the principles of the European Higher Education Area (EHEA). Thus, there is continuous virtual communication among students and lecturers.

The main goal of this subject is focused on the security of information infrastructures from a practical point of view. Due to the distance methodology, this course must adapt the traditional teaching/learning process into a more active virtual attendance and interaction among the learning community. This fact is even more relevant inside UNED's case due to its high number of students per course.

To describe the educational context, we must pay attention towards the main Learning achievements or Outcomes (LOs), detailed next:

- **LO1.** Understanding the Network Security Management (NSM) model and its associated best practices.
- **LO2.** Using a range of security open-source utilities oriented towards analyzing network traffic, in order to search intrusions, malfunctions or other kinds of vulnerabilities.
- **LO3.** Knowing and using the best utilities to generate, monitor, and manipulate network traffic, as well as performing recognition tasks.

Students may acquire these LOs, which related to practical competences o topics of interest, by fulfilling the subject objectives. These objectives are summarized in Table 1. Additionally, this table also correlates the contents of this course with its corresponding objectives and learning outcomes.

Due to the wide range of topics developed inside the course and its nature, the inclusion of practical activities is fundamental. The evaluation of this subject is composed by three practical activities and a theoretical exam. The experiment presented in this work is focused on the second mandatory practical activity. The main objective of this activity is the configuration of a firewall in order to protect a system following the security requirements of the scenario. During this activity the student work the following Topics (T):

- **T1-Security principles.** Students must take into account the basic security principles, such as minimum

privileges, in order to design a security access policy to the protected network in the described scenario.

- **T3-Logical security.** Students must analyse the presented scenario and they should determine the relevant role of the security policy under that circumstances.
- **T6-Cybersecurity policies.** As it is mentioned in the previous item, students must define a security policy that satisfies the objective proposed in the described scenario.
- **T7-Firewalls.** The main security countermeasure implemented in the scenario is a firewall. The firewall should be configure by students in order to accomplish with the designed security policy of network access.

Our proposed laboratory is flexible enough to host different scenarios where the student can accomplish all the previously described objectives. Thus, the student can perform the configuration of firewalls activity following the methodology of Plan-Do-Check-Act (PDCA), recommended by ISO 27001. Thus, the student should perform the following steps:

- 1) First, at the Plan phase, they must comprehend the activity objectives and search the needed improvement in the proposed scenario from the Cybersecurity point of view. This way, a security policy in a firewall must be designed by students in a flexible way.
- 2) Afterwards, in the Do phase, the designed policy has to be applied into the real firewall with configuration rules inside LoT@UNED. The platform provides a full controlled environment where lecturer can tackle the activity development (see Figure 7).
- 3) In the Check phase, the student must check that both the described policy and its implementation are in line with the objectives proposed in the scenario. Again, this procedure takes place inside the LoT@UNED platform, with the tracking of the course lecturers.
- 4) Finally, once the three previous phases are over, the Act phase is oriented towards learn from the experience. In order to fulfill this goal, students have to report their experience and make their own conclusions. This report is assessed, that offers feedback about it.

Students are provided with several resources that help them to successfully solve the activity:

ID	Name Practice	Service	Date Start	Date Finish	Email
1	Forensic Analysis	testforensa	01/12/2016 1:00:00	10/12/2016 1:00:00	hono@doc.uned.es
2	Vulnerability	testvuln	10/10/2016 0:00:00	10/12/2016 1:00:00	hono@doc.uned.es
3	Acción Forense Curso 2016-2019	AFor1619	10/10/2016 2:00:00	20/12/2016 1:00:00	hono@doc.uned.es
4	Firewall	testfirewall	10/11/2016 0:00:00	10/12/2016 1:00:00	hono@doc.uned.es

FIGURE 7. Faculty's view for tracking students' activity. Email accounts are obfuscated for privacy issues.

- A PDF context guide for the case of study and the proposed Cybersecurity tools used inside the activity.
- Several video-lessons that explains theoretical and practical concepts related with Cybersecurity policies,

TABLE 1. Correspondence among Learning Outcomes (LOs), Objectives (O) and Topics (T) for the Cybersecurity subject.

LOs	Objective	Topic
LO1	<p>O1-Understanding the relevance Cybersecurity as a design criterion in any Information Technology System.</p> <p>O2-Understanding the most common current problems of lack of Cybersecurity in Information Systems, applications and networks.</p> <p>O3-Describing and classify the most likely attacks inside Information systems, applications and networks.</p> <p>O4-Understanding the necessity of implementing a Cybersecurity policies in organizations.</p> <p>O5-Recognizing the importance for organizations of compliance of the Cybersecurity related laws, such as GDPR.</p> <p>O6-Understanding the relevance of a good Cybersecurity Management System implementation, by following the good practices of several international standards, ISO / IEC 27001 and ISO / IEC 27002.</p>	<p>T1-Security principles.</p> <p>T1-Security principles, T2- Network device security, T3-Logical security.</p> <p>T4-Attack methods against network and hosts.</p> <p>T2-Network Device security, T3-Logical security.</p> <p>T6-Cybersecurity Policies.</p> <p>T6-Cybersecurity Policies.</p>
LO2	<p>O7-Implementation basic Cybersecurity countermeasures in a proposed scenario.</p> <p>O8-Adapting basic Cybersecurity principles for network scenarios, and associated systems and data.</p> <p>O9-Use of Cybersecurity vulnerability scanners and interpretation of their outputs.</p> <p>O10-Being able to describe an access policy and its implementation using firewalls.</p> <p>O11-Selection and configuration of intrusion detection systems (IDS) inside Cybersecurity policy.</p> <p>O12-Be able of perform a basic analysis of network traffic using open source tools and sniffers.</p>	<p>T5-Basic defense measures.</p> <p>T5-Basic defense measures.</p> <p>T9-Vulnerability analysis.</p> <p>T7-Firewalls.</p> <p>T8-Intrusion Detection Systems (IDS).</p> <p>T10-Secure network design.</p>
LO3	<p>O13-Describing mechanisms for the suitable implementation of a Cybersecurity policies.</p>	<p>T10-Secure network design.</p>

its implementation with firewalls and ISO 27001 methodology.

- Forums and chats, so they can interact among students or with the course lecturers. These communications tools promotes debate about different approaches to the proposed scenario.

VI. RESULTS

A. DATA COLLECTION

Students were asked their opinion about performing the proposed activity with LoT@UNED, and their general experience in terms of considered factors, i.e. performance expectancy, effort expectancy, user attitude, social influence, facilitating conditions, and intention of use. Each statement of the survey was a five-point liker-type scale, ranging from (1) “strongly disagree” to (5) “strongly agree”. The format of this questionnaire is based on the UTAUT methodology [21], [24].

The LoT@UNED platform has been employed for a practical activity related to firewalls, which is integrated

in the instructional design of this subject. It was mandatory to pass the subject. The questionnaires were distributed among 129 students who finished this activity in 2018. A total of 246 students were enrolled in this subject. The sample size is enough for our purposes since opinions frequently repeat after a low number of questionnaires. An analysis of the reliability and validity of data has also been performed to check data goodness.

The data were analyzed using Python 3 and IBM SPSS Statistics 25 for the exploratory data analysis, as well as IBM SPSS Amos 25 Graphics for the confirmatory analysis, composed by the establishment of a SEM model, studying the defined hypotheses and validating a set of statistical indicators. An improved new SEM model and additional hypotheses, which are based on the studied factors and initial hypotheses, has been analyzed and validated in a satisfactory way, as detailed in the second part of the study. The employed algorithm for the discrepancy among factors and co-variances when calculating SEMs has been maximum likelihood.

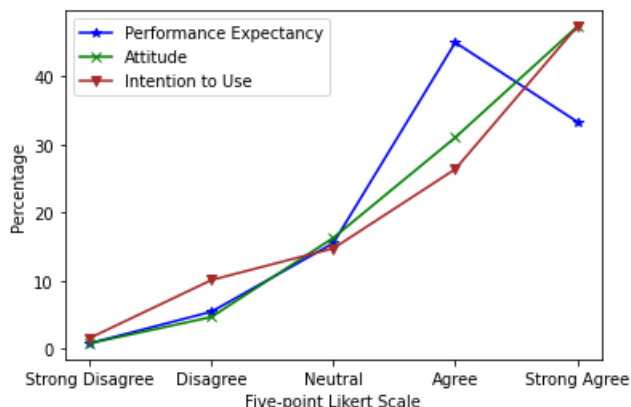


FIGURE 8. Comparison between the performance expectancy (perceived usefulness) and attitude of students with respect to the intention of use the LoT@UNED platform.

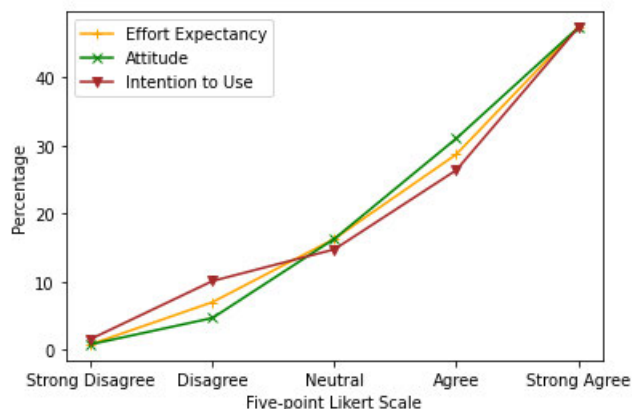


FIGURE 9. Comparison between the effort expectancy (perceived ease of use) and attitude of students with respect to the intention of use the LoT@UNED platform.

B. EXPLORATORY DATA ANALYSIS

In this exploratory analysis, we will compare how the technology proposed in this work (i.e., LoT@UNED) affects the intention to use it. It is noteworthy that this is the objective and exogenous factor with the UTAUT model. This factor determines the good perception of the user about the quality of the employed technology. The comparison is made in several steps, as detailed below.

Figure 8 compares the performance expectancy (the perceived utility of the technology), the users' attitude towards the new technology to be used, and the intention to use it in the future, in case the possibility arises for other subjects with practical activities. The y-axis represents the percentage of users who have valued these factors, whilst the x-axis represents the specific value answered in percentage. The scale is five-point Likert-scale: strong disagree (1), disagree (2), neutral (3), agree (4) and strong agree (5). These factors involve the H1 and H3 hypotheses.

As it can be observed in Figure 8, the three factors compared have similar increasing behavior. This behavior implies that most of the answers have been quite satisfactory (agree or strong agree) concerning the system's expected performance, the users' attitude is very positive, and the intention of using the platform for other purposes. The main difference between these factors lies in the performance expectancy (usefulness of the system). Some users who strongly agree with respect to their attitude and intention of use only agree with the system's usefulness. This issue is not unusual, since the LoT@UNED platform is constantly evolving, so the improvements proposed by users will be taken into account, both from the point of view of interface and the platform's operation.

As for accumulated results, over the 78% of the respondents were agree or strong agree with respect to the performance expectancy of the technology. These results are similar to the user attitude in terms of percentage, being always over the 78%. Nevertheless, the intention to use the LoT@UNED is a bit lower, since the 73% of the respondents answered the agree or strong agree options.

In addition to this, Figure 9 compares the factors of effort expectancy (perceived ease of use), the users' attitude towards LoT@UNED and the intention to use it in the future. Once more, the y-axis represents the percentage of users who have valued these factors, while the x-axis represents the specific value answered in percentage. In this case, most of the answers have also been quite satisfactory, and the three factors are very similar. In particular, the 76% of the respondents were agree or strong agree with the effort expectancy. The H2 hypothesis is the affection among this factor and the intention to use the technology.

On the other hand, Figure 10 shows in a comparative way the social influence and intention of use the LoT@UNED platform, as well as the facilitating conditions taking into account the use intention. The evolution of the compared factors is certainly different. The social influence is more neutral (see Figure 10a), since the practical activities in the LoT@UNED platform are individual. The facilitating access is more relevant (Figure 10b), users agree with the ease of access to LoT@UNED, but not totally agree. In particular, the 52% of the respondents were agree or strong agree with the social influence over the employed technology, and the 54% of the participants agree or strong agree with respect to the facilitating conditions of the technology. These factors are linked to the intention to use it with the H4 and H5 hypotheses, respectively.

On the other hand, Figure 11 provides the mean, median and standard deviation values for the different factors. Firstly, the mean values for all factors with a five-point Liker-scale are quite good. Most of them range from 3.93 to 4.13, with the exceptions of the social influence (with a value of 3.67) and the facilitating conditions (with a value of 3.40). The median values are slightly higher when comparing to the mean values, whilst the standard deviation values are over or lower than one. Thus the provided data are very reliable. Additional parameters for this data are studied in [42].

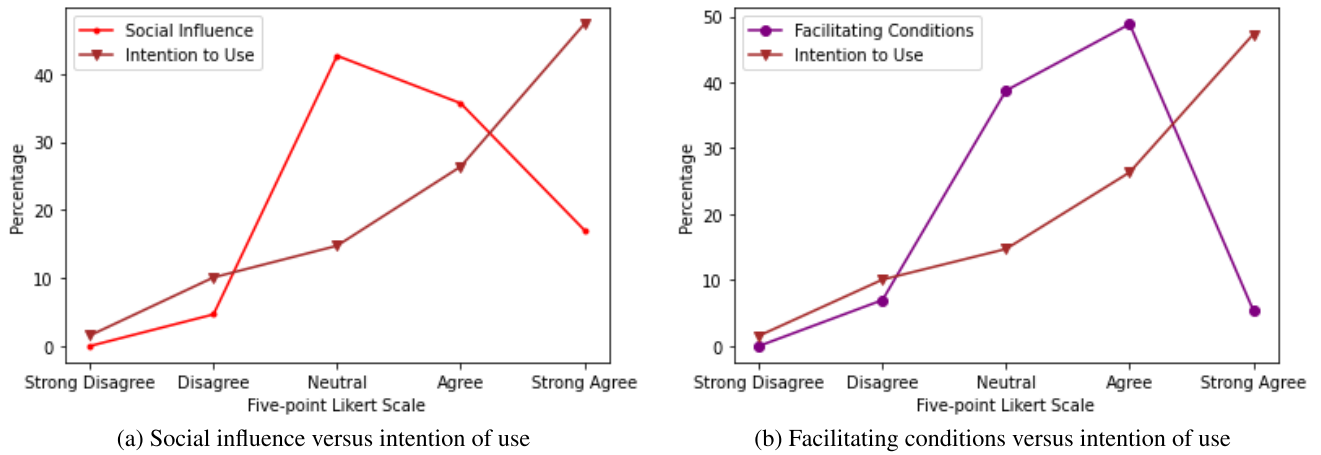


FIGURE 10. Comparison between the social influence and facilitating conditions with respect to the intention of use the LoT@UNED platform.

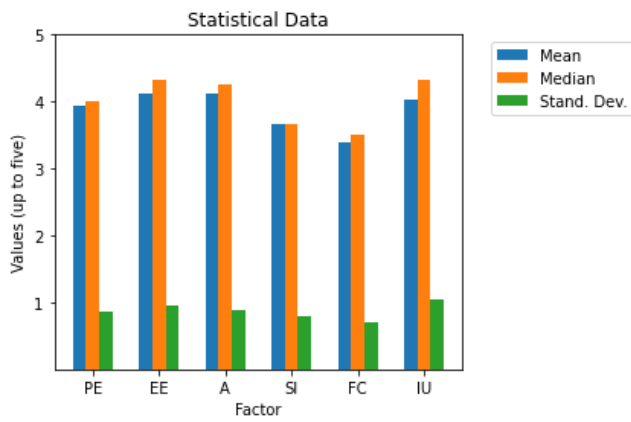


FIGURE 11. Mean, median, and standard deviation values for the measured factors (PE, EE, A, SI, FC, IU).

C. RELIABILITY AND VALIDITY

In order to perform a confirmatory factor analysis is very important to check the reliability and validity of the collected data in a statistical way. In this sense, Table 2 shows a set of psychometric characteristics. These values will complement the exploratory analysis performed above and corroborate data in ranges of normality. Remind that the considered UTAUT/TAM factors are performance expectancy, effort expectancy, attitude, social influence, facilitating conditions, and intention to use.

To analyze the correctness of collected data, Kurtosis and Asymmetry parameters have been calculated for each factor as observed in Table 2. The first indicator, Kurtosis, specifies the concentration of data for each factor around the average value, which would be the central point. In our particular case, this parameter is positive in four factors (data tends to the right side of the average value), whereas it is negative in the other two ones (data tends to the left side of the average value). For all factors, data distribution is near the central point, not being very scattered. Asymmetry can be seen as the degree of symmetry for each factor with respect to the

TABLE 2. Principal psychometric characteristics.

	Kurtosis	Asymmetry	Cronbach's Alpha	HTMT _{IU}
PE	0.96	-0.95	0.88	0.78
EE	0.15	-0.96	0.89	0.65
A	0.43	-0.93	0.87	0.86
SI	-0.92	0.21	0.89	0.62
FC	-0.04	-0.27	0.90	0.84
IU	0.01	-0.96	0.88	-

TABLE 3. Covariance matrix among factors.

	PE	EE	A	SI	FC	IU
PE	0.758	0.495	0.633	0.425	0.341	0.626
EE	*	0.908	0.519	0.398	0.394	0.593
A	*	*	0.800	0.437	0.387	0.717
SI	*	*	*	0.629	0.291	0.450
FC	*	*	*	*	0.504	0.396
IU	*	*	*	*	*	1.089

horizontal data distribution. Data tends to be a bit oriented to the left side for five factors with a consistent distribution.

On the other hand, the six associated factors related to the behavioral intention to use the LoT@UNED platform in the Cybersecurity subject have a Cronbach's alpha reliability coefficient of 0.902, when standardized elements with a value of 0.904. Additionally, the factors loading of Cronbach's alpha must be at least 0.70 or greater [27], [61]. Our six factors satisfy this premise, ranging from 0.87 to 0.90 (see Table 2). These values are considered as more than acceptable and reliable, by considering the literature [27], [42], [63].

The validity of factors has also been assessed. For the convergent validity, the AVE (Average Variance Extracted) values obtained for each of the six factors, all of them are higher than 0.50. Thus, validity is suitable [27], [70].

TABLE 4. Correlation matrix among factors.

	PE	EE	A	SI	FC	IU
PE	1	0.597	0.813	0.615	0.552	0.689
EE	*	1	0.609	0.527	0.582	0.597
A	*	*	1	0.616	0.610	0.768
SI	*	*	*	1	0.517	0.543
FC	*	*	*	*	1	0.535
IU	*	*	*	*	*	1

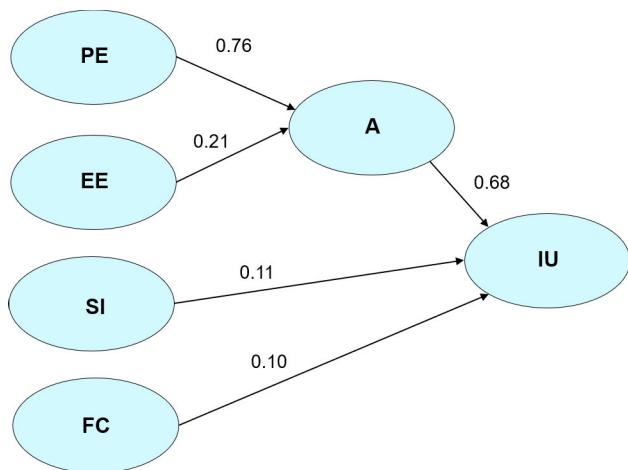
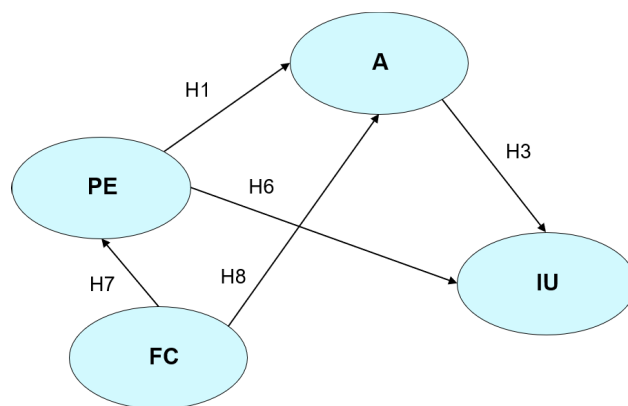


FIGURE 12. Validation of the SEM model for LoT@UNED with the UTAUT/TAM factors [24].

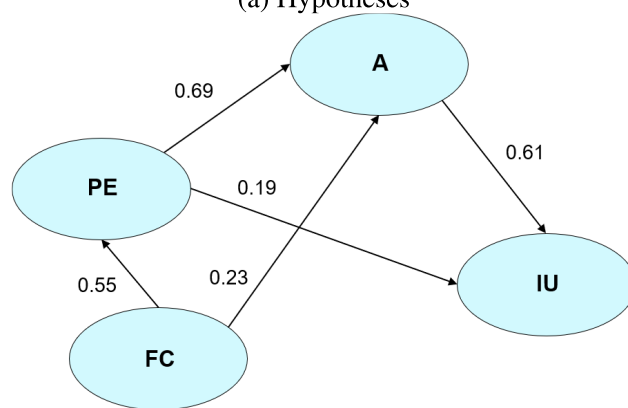
In addition to this, the Heterotrait-Monotrait ratio of correlations (HTMT) has been calculated for the outcome IU factor concerning the rest of the factors (see Table 2). The HTMT ratio must be less than 1.00 [71], [72]. Our $HTMT_{IU}$ ratios satisfy this premise. For the discriminant validity analysis, Table 3 also summarizes the co-variance matrix among all factors, whereas Table 4 summarizes the correlation matrix among them. These are in ranges of reliable normality. To sum up, it can be concluded that collected data are consistent, reliable and valid to perform a further confirmatory factor analysis [27], [73].

D. VALIDATING THE INITIAL SEM MODEL

The original hypotheses of the initial SEM model have been defined in 2, considering the H1, H2, H3, H4 and H5 hypotheses described above. Figure 12 represents the influence among these hypotheses. On the one hand, H1 shows that the students' performance expectancy (perceived usefulness) of the LoT@UNED platform clearly influences the students' attitude with a value of 0.76. This attitude also greatly influences the students' intention to use the platform (H3=0.68). There are strong links among these three factors, as expected from the exploratory analysis. As concluded in [74], the perceived usefulness is a key factor in the behavioral intention to use a system. In our case, indirectly, through the attitude toward the technology.



(a) Hypotheses



(b) Values

FIGURE 13. Proposing and validating a new SEM model for LoT@UNED.

On the other hand, the effort expectancy (ease of use) of students does not significantly influence the attitude (H2) with a value of 0.21. In a similar line, neither social influence nor facilitating access affect directly the intention of using the platform (H4 and H5), with the values of 0.11 and 0.10, respectively.

The Chi-square value is 216.112, and its relationship with the degree of freedom is 21.611. Both the goodness and comparative fit indexes are 0.596. The root mean square error of approximation is 0.401.

SEM-AMOS is also a useful tool to statistically analyze a set of fitting results when performing a Confirmatory Factor Analysis (CFA), in order to check its validity, consistency, and reliability [34], [57], [75]. Several goodness of fit strategies must be analyzed, such as Chi-square (χ^2), Chi-square / Degree Freedom (χ^2/DF), Comparative Fit Index (CFI), Goodness of Fit Index (GFI), Normed Fit Indices (NFI), Relative Fit Indices (RFI), Incremental Fit Indices (IFI), Tucker-Lewis coefficients (TLI), Adjusted Goodness of Fit Index (AGFI), Root Mean square Residuals (RMR) and Root Mean Square Errors of Approximation (RMSEA). Recommended cut of and threshold values for fit indexed are detailed in the literature [46], [53], [73], [76]. These recommended values will be detailed below.

Table 5 summarizes the goodness of fit indicators used to evaluate the initial SEM model using the UTAUT/TAM

TABLE 5. Statistical indicators for the initial SEM model.

Indicator	Obtained Value	Optimal Value	Satisfied
Chi-square (χ^2)	216.112	>0.5	Yes
Chi-square / Degree Freedom (χ^2/DF)	21.611	<3	No
Comparative Fit Index (CFI)	0.558	>0.90	No
Goodness of Fit Index (GFI)	0.596	>0.90	No
Normed Fit Index (NFI)	0.551	>0.90	No
Relative Fit Index (RFI)	0.327	>0.90	No
Incremental Fit Index (IFI)	0.563	>0.90	No
Tucker-Lewis Index (TLI)	0.338	>0.90	No
Adjusted Goodness of Fit Index (AGFI)	0.151	>0.09	Yes
Root Mean-square Residuals (RMR)	0.309	Near to zero (Perfect Fit)	No
Root Mean Square Error of Approximation (RMSEA)	0.401	<0.08	No

TABLE 6. Statistical indicators for our proposed SEM model.

Indicator	Obtained Value	Optimal Value	Satisfied
Chi-square (χ^2)	1.626	>0.5	Yes
Chi-square / Degree Freedom (χ^2/DF)	1.626	<3	Yes
Comparative Fit Index (CFI)	0.998	>0.90	Yes
Goodness of Fit Index (GFI)	0.994	>0.90	Yes
Normed Fit Index (NFI)	0.995	>0.90	Yes
Relative Fit Index (RFI)	0.969	>0.90	Yes
Incremental Fit Index (IFI)	0.998	>0.90	Yes
Tucker-Lewis Index (TLI)	0.988	>0.90	Yes
Adjusted Goodness of Fit Index (AGFI)	0.937	>0.09	Yes
Root Mean-square Residuals (RMR)	0.013	Near to zero (Perfect Fit)	Yes
Root Mean Square Error of Approximation (RMSEA)	0.070	<0.080	Yes

factors. The Chi-square value is 216.112, and its relationship with the degree of freedom is 21.611, which is not optimal. The goodness fit indexes (CFI, GFI, NFI, RFI, IFI, TLI) are not good since they are by far lower than 0.90. Even some studies indicate that these values should be higher than 0.95. Only the AGFI indicator is acceptable with a value of 0.151, higher than 0.09. Additionally, neither RMR nor RMSEA are optimal. For this reason, it is necessary to search for an improved SEM model which satisfies these statistical indicators.

E. PROPOSING A NEW SEM MODEL

For the proposition of a new SEM model, a set of hypotheses has been re-defined from [24] and [57].

First, we have previously checked that social influence does not affect the intention to use the system. The effort expectancy about the platform for our Engineers is not a problem. Students are more concerned with performance and/or in-depth facilitation conditions.

Therefore, we have removed from our SEM model the previously mentioned factors. Our new proposed SEM model is presented in Figure 13a. The specific hypotheses and their expected influence between the considered factors are then redefined and adapted to our proposed new SEM model as follows:

- **H6.** The performance expectancy (PE) of the LoT@UNED platform affects the intention to use (IU) it.
- **H7.** The facilitating conditions (FC) of the LoT@UNED platform affects its performance expectancy (PE).
- **H8.** The facilitating conditions (FC) of the LoT@UNED platform affects the user attitude (A) towards this platform.

The initial H1 and H3 hypotheses have been maintained within the framework of our proposed SEM model. As observed in Figure 13b, once more, there is a strong influence of the performance expectancy over the attitude toward the proposed technology (H1=0.69) and, indirectly, over the intention of use it for future purposes (H3=0.61). This is quite similar to the initial SEM model studied above.

For the new H6 hypothesis, there is some direct influence of the performance expectancy with a value of 0.19, although it is not very strong since an attitude factor is very relevant in our study. Furthermore, despite the fact that students' facilitating conditions are not particularly relevant with the intention of use (H7), this factor strongly influences the performance expectancy of LoT@UNED with a value of 0.55. In other words, the ease of access to the technology is significantly related to the students' perceived usefulness.

The H8 hypothesis is also important, as it reflects the affection of the facilitating conditions of LoT@UNED with

respect to the students' attitude, with a value of 0.23. That means whether a student thinks that access to the platform is more or less complex, his or her attitude towards it may be more or less negative.

Table 6 shows the statistical indicators which are calculated for this model, in order to check its reliability. As it can be observed, all these values are satisfied. The Chi-square value is optimal, since it is 1.626, and their relationship with the degree of freedom with the same value. Both the CFI and IFI values are 0.998, higher than the threshold of 0.9. Some studies even recommend them with a higher value of 0.95. The rest of goodness fit indicators are optimal and in ranges of normality (GFI=0.994, NFI=0.995, RFI=0.969, TLI=0.988, AGFI=0.937). The RMR indicator is near zero, with a value of 0.013. RMSEA is also very suitable, which is lower than 0.08.

VII. CONCLUSION

The manuscript describes first a self-developed platform, named LoT@UNED, which covers several topics of interests, ranging from edge to cloud computing. The most relevant topics are IoT, programming, and security. The flexibility of the platform involves acquiring practical competences of these subjects, by means of a set of remote and virtual laboratories, in an integrated way with the corresponding on-line courses. The objective is to increment the quality of courses with a distance methodology. The LoT@UNED platform has included a set of sustainable capabilities (scalability, availability, security) and supporting data privacy with GDPR to tackle the SDG4 challenge for quality education. The importance of this SDG is great, and it has been increased during the COVID-19 pandemic.

Firstly, an exploratory data analysis has been conducted to study the reliability of the gathered data and perform an initial exploration of the factors that influence the students' behavior when using the LoT@UNED platform in the instructional design of a subject. In this sense, the most relevant UTAUT/TAM factors have been evaluated to analyze the perceptions and quality of the proposed technology.

Secondly, an initial structural equation model is studied to check the impact of IoT cloud technologies on students' signs of progress after following the UTAUT/TAM model. This way, a new set of hypotheses has been appropriately analyzed to check the influence among the explored factors. The reliability and validity of data are also analyzed. Moreover, a set of statistical indicators have been calculated, such as χ^2 , χ^2/DF , goodness fit indexes (CFI, GFI, NFI, RFI, IFI, TLI, AGFI), RMR, and RMSEA, to evaluate the proposal. Obtained results reveal that the initial SEM model does not satisfy these statistical indicators.

Therefore, a new refined SEM model has been proposed by removing some initial hypotheses and factors and re-defining new hypotheses. The influence among factors with these hypotheses are studied in deep and the statistical indicators are calculated to check the suitability and reliability of the improved model. The obtained results prove that all indicators

are now satisfied, reaching optimal values in ranges of the expectancy, which are even better than expected after our initial analysis.

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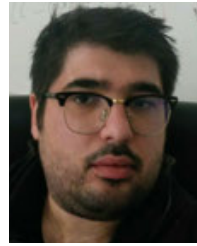
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