VIOT_Lab: A Virtual Remote Laboratory for Internet of Things Based on ThingsBoard Platform

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***Abstract*—In March 2020, due to the pandemic linked to the COVID-19 virus spreading, all in-person teaching activities planned at the University of Salerno were suspended. This sudden suspension has forced the academic world to rethink in a short time the didactics and to modify teaching styles and approaches, especially in those courses in which laboratory activities were planned. This article will be presented the experiences made in the Computer Networks and Protocols for the Internet of Things (IoT) course. The course includes a significant laboratory component where students must put into practice what they learned during the theoretical lessons. In particular, the laboratory exercises involve using specific equipment and devices that can build digital ecosystems for the control and management of well-defined operational contexts difficult to reproduce virtually. Therefore, to give continuity to the didactic activity, it was necessary to redesign the entire exercise system preserving the original educational objectives.**

Keywords—e-learning; virtual laboratory; Internet of Things.

I. Introduction

Although the term is increasingly used, it is not easy to provide an unambiguous definition of e-Learning [1]. E-learning can be defined as the "use of Information and Communication Technologies (ICT) to enhance the quality of learning through access to resources and services and long-distance collaboration and interchange" [2], [3]. There are many studies in the literature that have defined e-learning from different perspectives. Sarah Guri-Rosenbilt defined e-learning as an electronic support medium used for various learning purposes that adds functionality to the presence and distance [4]. In [5], Ruiz, Mintzer, and Leipzig defined e-learning as "the use of Internet technologies to improve performance and knowledge." While in [6], Clark and Mayer in 2016, defined e-learning as "instruction" delivered via digital devices with the intent to support learning." Finally, Arkorful and Abaidoo [7], in 2015, define e-learning as "the use of information and communication technologies to enable access to online teaching and learning resources." From what has just been discussed, e-learning is not identified with a single technology or methodology but rather various flexible, evolving solutions. Because communication takes place in a digital and networked context, compared to face-to-face teaching, there are new possibilities: The digital materials can be drawn on, taken up, modified, and integrated; this makes it easy to reuse work already done and to remodel teaching paths. The speed of student-tutor interaction allows for possible personalization of learning rhythms and high-quality feedback to the student. Moreover, the very nature of computer-mediated communication makes it possible to establish relationships of sharing and collaboration, with a plurality of subjects who can interact in a virtual classroom or online workgroups, in a more articulate form than is possible in face-to-face relationships [8].

Initially, there was an attempt to reproduce the pre-existing models in distance learning, showing little attention to the specificities offered by the particular communicative condition: e-learning was identified with an efficient system of transmission of lessons in real-time. What prevailed, therefore, was a distributive meaning of the concept of e-learning. With time, however, orientations that are more sensitive to the specifics of the medium are gaining prominence. These solutions put an active online student at the center, engaged in dialogic interaction with tutors and fellow students. For many years now, we have been witnessing a growth in collaborative learning models. This orientation transforms knowledge into a process of active construction, in the forms of sharing and collaboration, even impromptu [9]. Following the events related to the COVID-19 pandemic, there has been a veritable explosion of distance learning. Given such a risky and complex situation, the only sudden and compulsory option fell on distance learning. This real "crisis" linked to the emergency we are experiencing has fostered a greater awareness of teaching methods in the most virtuous cases. Therefore, we can say that the pandemic is setting the conditions for a fuller understanding of the potential of online learning and as a tool that has made it possible to guarantee continuous and accessible education in an emergency. It is necessary to note that, although we will not discuss it here, we should not overlook the negative aspects of a situation in which the massive adoption of distance learning was not the result of choice but instead of an imperative need.

The study presented by Prestiadi [10] takes the first steps in determining the effectiveness of using e-learning as a distance learning strategy during the coronavirus pandemic. The study shows that the use of e-learning can be effective in improving student learning and interest. In addition, e-learning has advantages in other aspects, such as flexibility concerning learning time. In light of this, what was traditionally considered the ideal format for teaching (face-to-face teaching in presence) is not always so because it involves, in addition to the need to be all in the same place at the same time, several limitations. For example, in presence, communication is necessarily sequential with minimal possibilities for sharing and collaboration. A further study, conducted by Ray and Sanjeeva [11], emphasizes the importance of virtual labs. Regular e-learning courses alone cannot provide adequate skills regarding laboratory experiments or scientific data analysis. In this sense, virtual labs have added a new dimension to digital learning. Virtual labs also become advantageous from an economic point of view. Organizing expensive and sophisticated laboratory facilities in academic settings often remains challenging, particularly in developing and underdeveloped countries with limited educational budgets. In this sense, the spread of technology has led to the spread of a large number of low-cost devices with the intent to monitor and reproduce reality in order to improve the environments in which we live. Such a paradigm, known as the Internet of Things (IoT) [12], represents the key to future approaches [13].

Moreover, the wide availability of low-cost IoT devices is an essential condition to support creativity, allowing students [14] to control and build systems that are always different and suitable for countless situations. In fact, a modern distributed system could support students in learning remotely, initiating them into the IoT paradigm through the use of coordinated devices using IoT context management platforms. Such a proposed system could support students in seeking solutions peculiar to the IoT paradigm, allowing them to continuously and immersively monitor their environment, transfer monitored data into a collection environment, and process this information to perform actions that address (or prevent) a wide range of needs. In this acquisition-processing-execution cycle, the learning objective, in line with IoT, is the ability to move from a mere automated process to an intelligent process. This process refers to supporting learners in equipping the reference scenarios with cognitive capabilities, making the environments capable of reacting dynamically.

This paper presents a significant experience related to collaborative forms of learning experimented during the COVID-19 era, specifically through a virtual remote lab built using the Thingsboard[1] [15] platform, an environment for managing IoT applications. After the description of the environment implemented by us and the training model adopted, it will be presented and discussed the results derived from the submission of satisfaction questionnaires, with particular attention to the possibility of working collaboratively in virtual groups in the current situation that makes it difficult or impossible to co-presence within the same physical space.

II. The Proposed Approach

This section aims to present the proposed approach. Therefore, the research objectives, the methodology adopted, and the instrumentation necessary to perform the proposed activity will be presented. The presented laboratory experience, performed during the emergency period, attempted to address some specific objectives. The main objective was to develop a remote learning environment for laboratory activities based on the Internet of Things, allow teaching continuity, and improve students' learning experience. The other objective was to evaluate the impact of this methodology on motivation and learning compared to established teaching methods. To ensure educational continuity during the pandemic period, a virtual learning laboratory was designed and developed through the steps shown in Figure 1. The learning lab environment aims to provide preliminary training on the Internet of Things to students attend the "Computer Networks and Protocols for the Internet of Things (IoT)" course.

The idea was developed in the first phase of the project, related to General Design. A literature review supported the definition of the objective of the lab project. The virtual lab aims to provide the tools for an understanding of the IoT paradigm through the study of the main protocols and platforms, with particular reference to the application aspects, through the use of embedded devices. The laboratory teaching method was focused on the centrality of the learner, which helps to make them aware of the learning processes for the achievement of clear objectives without depriving them of the discrete guidance of the teacher [16]. In addition to interacting with the remote lab, students were still supported by the traditional teaching approach. The innovative aspect consists in the fact that the lab activities allow the student to interact, even if remotely, with the sensors giving the confidence to deal with such interactions in the future, playing a crucial role in achieving learning. Finally, in the first design step, all activities to be performed remotely were designed. In the second step, attention was instead paid to the design of the physical spaces of the lab and the choice of technologies to be used. To allow students to work remotely, it was necessary to physically prepare the equipment such as sensors, electronic boards, cameras, and objects functional to the activities. In this phase have been chosen the necessary equipment and spaces to allow students to work remotely. Particular attention was paid to the choice of the boards to work on, the main sensors to interact with, and the instrumentation to visualize the activities carried out remotely. The boards used were Raspberry Pi 4 (Model B 4GB ARM-Cortex-A72 4X 1.50 GHz, 4 GB RAM) - Careful attention was also paid to the choice of the most appropriate environment to support the IoT. This environment, in fact, must allow the connectivity of devices through typical IoT and communication protocols

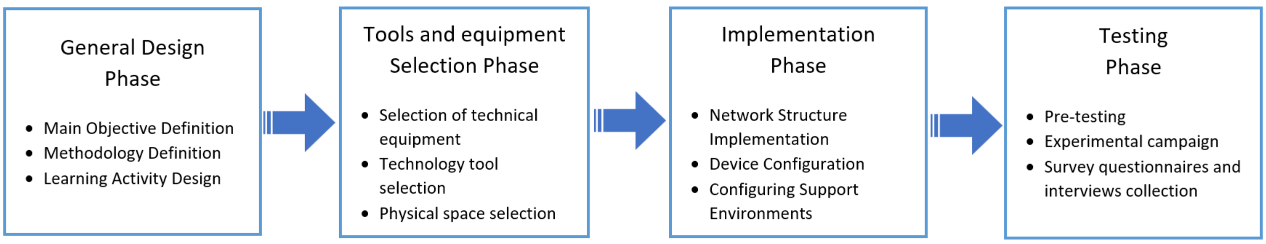

Figure 1 The proposed Approach

[1] https://thingsboard.io/

such as MQTT, CoAP, and HTTP. The choice for this environment has fallen on the ThingsBoard platform, an open-source platform that allows data collection, processing, visualization, and device management. To equip the laboratory with this platform, it was necessary to purchase a server that would allow the implementation of the environment. The third phase was focused on the implementation, i.e. the configuration of environments and devices. In particular, a network dedicated to the laboratory has been implemented, which can be reached from the outside through a VPN for security reasons. The electronic boards have been configured by adding the operating system and connecting them to the network and to the various sensors. Finally, the ThingsBoard platform was configured to manage data remotely by setting up a dedicated server.

The last step was the testing phase. After a first and quick preliminary test aimed at ensuring the functioning of the equipment, the students were able to take remote control of the equipment and carry out the laboratory teaching activities. At the end of the assigned activities, they were given questionnaires and interviews to assess the degree of learning, motivation, and satisfaction regarding the work done.

A. *ThingsBoard Platform*

ThingsBoard is an Open-Source platform designed for device management and data collection, processing, and visualization for IoT solutions[2]. It enables device connectivity via IoT industry-standard protocols (MQTT, CoAP, and HTTP) and supports both cloud and on-premise implementations. The services offered by this platform are:

- Securely provision, monitor, and control Internet of Things entities using rich server-side APIs. It defines the relationships between devices, resources, customers, or any other entity;
- Collect and store telemetry data in a scalable and fault-tolerant manner. It allows visualizing data with built-in or custom widgets and flexible dashboards. Such dashboards can be shared with customers;
- Control devices using remote procedure calls (RPCs);
- Send device data to other systems;
- Define rule chains for data processing. Allow to transform and normalize device data and trigger alerts on incoming telemetry events, attribute updates, device inactivity, and user actions;
- Build a ThingsBoard cluster and achieve maximum scalability and fault tolerance with the micro-services architecture it offers.

ThingsBoard is designed to be:

- Scalable: horizontally scalable platform, built using leading open-source technologies;
- Fault-tolerant: no single point of failure, every node in the cluster is identical;
- Robust and efficient: a single server node can manage tens or even hundreds of thousands of devices depending on the use case. The ThingsBoard cluster can manage up to millions of devices;
- Resilient: data is not lost. ThingsBoard supports various queuing implementations to provide high message durability;
- Customizable: it is easy to add new functionality with customizable widgets and rule chains nodes.

The Thingsboard platform is versatile; it is possible to run the platform as a standalone application or micro-services set. The ThingsBoard back-end is developed in Java, although there are also some Node.js-based micro-services. The diagram in Figure 2 shows the key components of the system and the interfaces that are provided.

III. Experimental Phase

This section aims to present the case study with the specification of the number of participants and the activities carried out to validate the proposed methodology. Twenty-

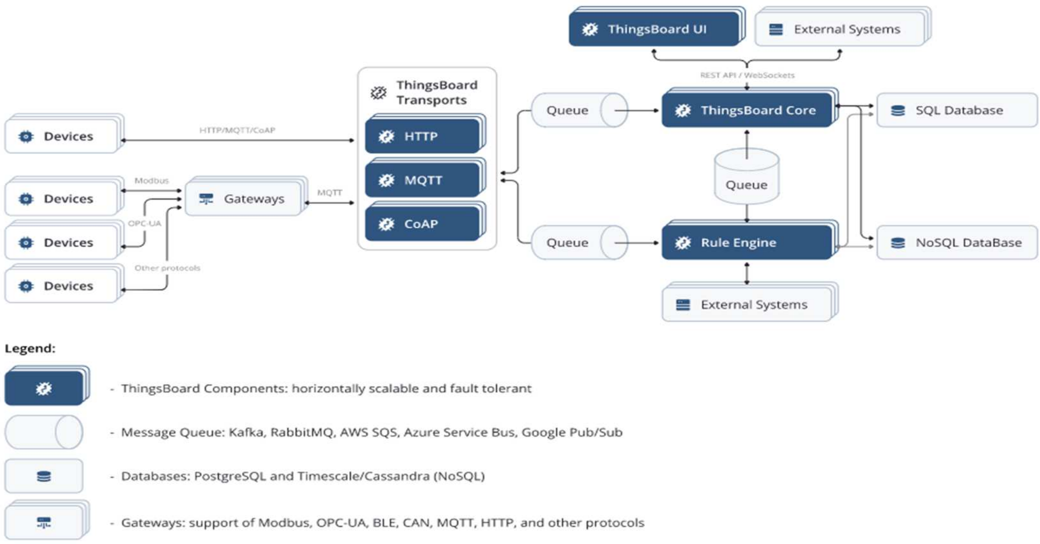

Figure 2 ThingsBoard Architecture

[2] https://thingsboard.io/docs/reference/

five students of the course of Networks and Protocols for the Internet of Things held at the University of Salerno took part in the experimental campaign. The sample includes students attending the first year of the Master's degree in Electronic Engineering, therefore, without previous knowledge in the Internet of Things. The students were divided into groups of 5, merged randomly. Each group was assigned a different project activity.

The course has been structured, starting with a theoretical part that has covered about 60% of the available hours. This section explained fundamental topics of computer networks and protocols useful to understand the IoT paradigm. This theoretical part was followed by the assignment of project activity for each group required to implement a virtual environment of experimentation based on the IoT paradigm. In particular, five tracks were assigned. The tracks covered different application areas and all required monitoring an environment using different sensors. Each track required to be able to intervene, according to some rules, through actuators to change specific conditions of the monitored environment. In addition, it was required to virtualize everything through the ThingsBoard environment allowing users to visualize the sensors and intervene on appropriate actuators. The areas of work were as follows:

- Swimming pool monitoring
- Agricultural field monitoring
- Museum monitoring
- Home environment monitoring
- Vehicle monitoring

A small physical environment was envisioned with a Raspberry Pi, several sensors, and a camera to visualize the environment for each track. In addition, wherever possible, conditions were reproduced to simulate the real environment. For example, in monitoring a swimming pool track, the remote environment was equipped with a small pool with water and several sensors; in monitoring agricultural land track, small seedbeds were set up with soil moisture sensors, irrigation pumps etc. Where it was not possible to reproduce the conditions, scripts capable of emulating sensors or entities within the virtual environment were implemented. Students were asked to exploit the Thingsboard environment to connect sensors by creating "devices" objects, creating dashboards to visualize sensor parameters, or interacting and monitoring actuators. Finally, it was also required to exploit the modules "rule chain" to generate rules that could alert or control actuators depending on the status of some sensors.

After the exercise and the exam, the students have made an anonymous questionnaire to evaluate the activity. The questionnaire questions were designed in the light of several scientific works [17] [18] to monitor three primary parameters: cognitive load, motivation, and satisfaction. The following are the statements of the questionnaire.

A. Cognitive load

1. The development of the project activity was within my reach
2. I had to put in the right hours of work to achieve the desired results
3. The instructional activity appeared suitable to follow and understand

B. Motivation

1. It is important for me to learn and understand the topics covered in the course.
2. I would like to learn more about the topics covered in the course
3. I hope to use what I learned in a future job

C. Satisfaction

1. The project activity was of interest to me
2. The lectures and materials provided adequately supported me to interact with the remote lab
3. I did not have any problems using the equipment provided remotely

After the questionnaire, students were asked to leave, always anonymously, an optional comment on the experience, use, and interaction with the remote virtual laboratory.

IV. Experimental Results

This section reports the results of the design exercises and the results of the anonymous student questionnaire. The 25 students interacted with the remote lab during April-June 2020, taking the final exam in July 2020.

The students' design exercises, in all cases, reported high quality. The students have well analyzed, understood, and carried out the assigned activity. Despite the difficulties experienced in the lockdown period, it was possible to notice a creative approach to problem-solving in all cases. This is evidenced by some of the dashboards shown in Figure 3. Students have shown individual creativity in solving problems due to the particular condition of working remotely. In particular, in vehicle monitoring track, the students implemented a script that simulated the routes designed using real points extracted from Google Maps. In the case of museum monitoring, where people counting was required, students implemented a script that allowed the real acquisition of images; these could be transmitted to the system by file or acquired by webcam to recognize and count the number of people. In many cases, students spontaneously devised additional modules that would allow, for example, system interaction via Telegram chatbots or sending alerts via email or text message. After the examination, the students were asked to answer the questions reported in the previous section; the answers were associated with an expression of liking according to the Likert scale ("Totally disagree"-TD, "Disagree"-D, "Undecided"-U, "Agree"-A, and "Totally Agree"-TA). The results obtained are reported in Table 1 and Figure 3.

TABLE I. QUESTIONNARIE SECTION RESULTS

SECTION	TD	D	U	A	TA
A	14	10	6	20	25
B	3	7	7	27	31
C	3	9	3	13	47

The results of the questionnaire show as the proposed activities to students are in line with the cognitive load entrusted and as the virtual remote laboratory has helped to keep alive the motivation of students despite the particular pandemic emergency period. In addition, the section regarding the satisfaction index was the one with the most positive feedback, and the most used question was C1 (The project activity was of interest to me).

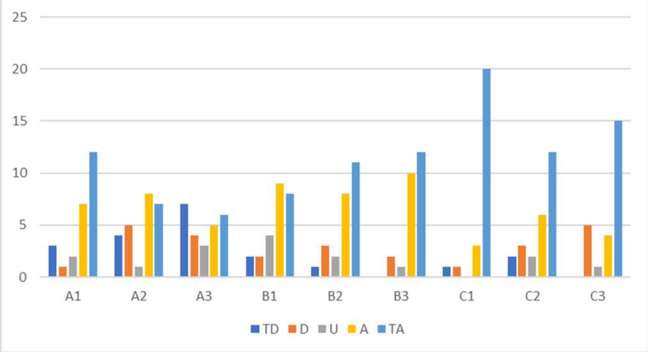

Figure 2 Questionnaire trends.

Further confirmation emerged from the analysis of the general comments requested about the remote lab experience. In fact, about 90% of the comments had a very positive connotation. The strengthening of creative skills and motivation to learn is also evidenced by additional and free comments from many students, who felt it was appropriate to thank the commitment of the research team in implementing the remote lab in this complex emergency they are experiencing.

Another objective value was the grades obtained by the students. In fact, a general increase in grades was noticed and increased about 30% in the achievement of the highest grade. In general, many students showed much interest in the activities carried out. In some cases, they spent more time than expected to improve and complete the assigned project exercise with improved aspects by their own choice.

V. CONCLUSIONS

The purpose of the article was to propose a new educational experience to cope with a health emergency. For this purpose, an IoT-based remote learning environment for laboratory activities was developed. The environment was designed to enable teaching continuity and improve the learning experience of the students. In this way, the didactics carried out emerged as an evaluative experience, especially for the impact of this new methodology on motivation and learning compared to established teaching methods.

This didactic experience was based on collaborative learning, expressed in working in virtual groups that allow for fruitful collaboration. In fact, for reasons of emergency and logistical reasons, the latter often remains challenging to implement within the same physical space. In addition, much space was given to the centrality of the learner, leaving a margin of creativity concerning the parameters assigned for the performance of the task. The results obtained have been strongly encouraging and encourage to continue to invest in this direction. The educational investment in the virtual laboratory based on the IoT has returned significant results in educational return and has offered a unique opportunity for change in the educational field.

In the future, we intend to extend the experimental campaign and investigate these new educational modes through advanced techniques [19], such as the use of chatbots [20], to support students in their learning further.

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