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# Open-source IoT lab for fully remote teaching

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**Abstract.** In the era of Industry 4.0, the concept of IoT has pervaded every sector of manufacturing, promoting hyperconnectivity as an enabling status for effective communication between company departments, as well as real-time monitoring of the status of manufacturing resources. The Coronavirus pandemic, due to the SARS-CoV-2 virus (COVID-19), confirmed the advantages provided by an IoT ecosystem in the worldwide economy. The role of universities in the development and use of this technology is twofold: on the one hand, the research activity supports the digital transformation of enterprises, and on the other hand the teaching activity trains the new managers of the future. Therefore, this work proposes a didactical activity in which students are guided to the creation of an IoT system that has several advantages: it is easy to develop, it uses only open-source components, and it includes all the necessary modules for the development of a real Industrial IoT (IIoT) system. Thanks to this experience, the students acquire different skills: (1) they operate on the hardware part of the system using sensors and actuators connected to a Raspberry Pi; (2) they develop and connect PostgreSQL database; (3) they generate an automation algorithm with for intelligent data management; finally, (4) they design a Human-Machine Interface using dashboards and social chat. The scope of this lab is not focused to university teams only. It is also accessible to high school students thanks to drag and drop programming (Node-Red) and tools (Telegram) close to the students everyday life. A further contribution of this project is to provide a method of managing a course that can be conducted entirely remotely as demonstrated during the current pandemic period.

**Keywords:** IoT; Education; Remote education; Industry 4.0

## 1 Introduction

The Internet of Things (IoT) represents a new frontier of industrialization, so much so that it is necessary to distinguish between the general concept of IoT and the Industrial IoT (IIoT). In the first case, a consumer-oriented concept, the focal points are people, home applications, consumer electronic devices, cars, computers, and many other everyday objects. IIoT, on the other hand, creates opportunities for enterprises, manufacturing plants, or entire sensor networks.

IIoT is a concept that should help in optimizing operational effectiveness and industrial production, in creating further growth, and in improving the competitiveness of international companies. Thanks to the huge amount of data that can be collected from

the network of interconnected machines and sensors, it is possible to improve the entire production chain, analyze in detail the weaknesses of the system and exploit the technology to recover the competitive advantage that the industries of the most developed countries seem to have lost with globalization.

It is expected that in the upcoming 10 years, there will be 3.5 million jobs available in manufacturing; however, less than half of them will be filled with people with the right abilities [1]. A well-qualified human resource will be now than ever important, and universities will play a key role in training the future workforce. Students of today and tomorrow need to have knowledge and abilities useful for facing a highly technological and interconnected environment [2]. Competencies that need to be developed in 4.0 students include interdisciplinary thinking, decision making, problem-solving, cultural, and intercultural skills, and commitment to lifelong learning [3]. A fundamental hard skill that engineers must possess is advanced analytics. In addition to basic knowledge, skills and competencies in innovation, analysis, and problem-solving play more important roles. These will allow them to analyze large data sets from many sources, optimize production processes, and support real-time decision making [4].

The objective of this paper is to explain the design of an IoT laboratory that allows students to (1) learn the basics of developing an IoT platform, (2) practice setting up a lightweight publish-subscribe messaging protocol, (3) understand basic data analysis and data visualization techniques to monitor industrial assets by processing data from sensors, (4) try their hand at developing a chatbot. An additional goal of this work is to design the entire teaching activity through the definition of a Cyber-Physical System (CPS), according to the formal definition of [5], that includes teachers, classroom, and all resources involved in the process. With respect to this goal, this paper tries to address two open points identified in the literature introduced in the next chapter: the detailed description of how to structure an IoT course for science students but new to this topic, and the design of a course that is didactically effective while being completion delivered remotely.

This article is structured as follows. Section 2 presents the state of the art of didactical activities in this sector and the description of our contribution on this topic. Section 3 describes all the technologies used to build the laboratory activity and how they are used together to build the didactical IoT system. The design of the didactical activity and strategies to evaluate the class are summarized and described in Section 4. Finally, Section 5 draws conclusions including results in terms of student's satisfaction and future works proposition.

## **2 Conceptual background**

In the last ten years there has been a growing interest from the scientific world in the design of practical training activities for the introduction of industry 4.0 concepts in universities but even more so in schools. The scientific output is so large that the literature review focused on review articles. This research work was necessary in order to analyze the methodologies of teaching technical subjects, the main software and

hardware tools used for courses on computer networks, and the criteria for evaluating the efficiency of teaching.

[6] aims to identify the key technologies of Industry 4.0 that have been ill-defined by previous researchers and to enumerate the skills required by Industry 4.0. Thirty-five disruptive technologies and 13 key technologies were quantified: IoT, big data, 3D printing, cloud computing, autonomous robots, virtual and augmented reality, cyber-physical system, artificial intelligence, smart sensors, simulation, nanotechnology, drones, and biotechnology.

[7] aims to identify the dimensions present in the literature on the relationship between Organizational Learning and Industry 4.0 trying to clarify how learning can be understood in the context of the fourth industrial revolution. In addition, future research directions are also presented. Nine dimensions have been identified between Organizational Learning and Industry 4.0: management, Industry 4.0, general industry, technology, sustainability, application, industry-university interaction, education and training, and competency and skills. These dimensions can be viewed in three main constructs: learning development, Industry 4.0 structure, and technology adoption.

[8] is dedicated to the study of the possibility of applying augmented reality technologies in the field of engineering education. In addition, the paper exposes the prerequisites for the creation and development of Industry 4.0, reflects on the problems of engineering education and future trends, explains the concept and technology of augmented reality, and analyzes the reason for its relevance and timeliness of its application in the process of professional education of engineers of different industrial departments considering its advantages and disadvantages.

[9] presents the results of a data collection regarding the educational impact of Industry 4.0 technologies in public schools in Catalonia. The results show that schools see the development and implementation of technologies that leverage Industry 4.0 as necessary for the classrooms of the future, always based on knowledge and pedagogical principles. Furniture, lighting, acoustics, and air quality must be regulated through a smart classroom.

The purpose of [10] is to provide an overview of the relatively new approaches explored primarily in the UK and Australia in higher education (HE) and to propose a framework with selected vocational training pathways for the tertiary education system in the Australian context. The implementation plan postulated by the reports of recent studies conducted in the UK apprenticeship system is intended as a guideline to facilitate a sustainable and technical career with three pillars of innovation, integration, and collaboration to improve the employment outcomes required by the digitized economy in Australia.

In the work [11], it is questioned whether the current educational infrastructure can seize the opportunity to build and oversee the requirements necessary to enable IoT to enhance the educational experience for any age. These challenges include ethical constraints (e.g., student privacy), technical constraints (such as big data captured from a wide range of heterogeneous sources), economic constraints (e.g., the added cost of technology in education), and physical constraints (such as available technology and communication channels within schools). Regardless of these challenges, and based on

the systematic literature review, the authors assert that IoT can significantly support pedagogical processes for all interconnected stakeholders (faculty, students, and staff) as well as all resources involved (libraries, classrooms, or labs). Jurisdictions and educational institutions should welcome (not prohibit) the personal devices that students bring into the classroom and should allow students to use them as learning tools to capture information faster and accelerate learning. Beyond that, it's clear that the IoT is poised to radically transform education. Because of this ubiquitous nature, schools and academic institutions are now looking to incorporate IoT into educational activities.

The main purpose of [12] is to analyze the use of the Internet in undergraduate education from a bibliometric perspective. To analyze scholarly works, scientific mapping strategies were used, for example, exploring co-words and co-authors in works on this topic. A total of 5118 papers indexed in the Web of Science database were analyzed. The most relevant topics are "e-learning", "systems" and "Internet of Things".

[13] presents a very interesting table that analyzes the evolution of teachers, students, learning processes and organization, and content up to the fourth stage, which is the one contextual to Industry 4.0.

[14] demonstrates the suitability and practicality of using advanced open-source tools such as the Raspberry Pi and Node-RED for teaching and learning the Internet of Things (IoT) topic within a new Data Engineering course in the Faculty of Engineering and IT at the Sydney University of Technology.

The literature review is presented to show the results of several papers in order to validate some of the tools and methodologies used in the course described in this manuscript. Few of the papers presented provide a complete and in-depth description of the structure of an IoT course, and none of them have been contextualized in a pandemic scenario where remote learning activity needs to be considered.

### **3 Design of the course**

Industry 4.0 promotes the digitization and digitalization of manufacturing and production related industries, this enables new ways of production, value creation and real time optimization. These new ways are guided by information systems where the real touchable world get connected to the Internet to be integrated with the cyber-space. The object of the IoT lab proposed by authors is teaching students concepts and techniques used to design and develop an IoT system with references to the manufacturing sector, where the class and all the tools used during the course can be considered a single CPS of which an in-depth description follows. This questionable choice was made in order to create a narrative of the course for students that tries to follow the technological concepts exposed in the course itself: in fact, the set of agents and processes involved in the class and the technologies used represent themselves a CPS managed through an IoT platform.

### 3.1 Taxonomy of educational objectives

The taxonomy of educational objectives is the framework to organize the expected results of the training activity, i.e., what we expect students learn. For this course, a revision of Bloom's taxonomy proposed by [15] is used in this work. In the revised one, any objective is represented in two dimensions shown by **Table. 1**, called taxonomy table: knowledge and cognitive process dimensions. The knowledge dimension is structured with the following subcategories: (A) factual knowledge is given by the basic elements of the discipline, (B) conceptual knowledge is given by the interrelationships among the basic elements, (C) procedural knowledge answers how to do something, and (D) metacognitive knowledge involves knowledge about cognition in general, i.e., having internalized the notions learned in one's own cognitive processes. The cognitive process dimension is made by the following subcategories: (1) remember refers to the long-term memory, (2) understand refers to determining the meaning of instructional messages, (3) apply refers to carrying out or using a procedure in a given situation, (4) analyze refers to detecting how the parts relate to one another, (5) evaluate refers to making judgments based on criteria and standards, and finally create refers to putting elements together to made new solutions.

Therefore, **Table. 1** is a formalization of the aims of the proposed course that are:

- providing clear definitions and concepts of the basic elements of IoT (remember a factual knowledge);
- giving the opportunity to apply this concept developing a simple prototype (apply the factual knowledge);
- understanding and discussing critically about the complexity of developing a system able to connect huge and heterogenous agents and to monitor and control them (understand, analyze, evaluate and create conceptual knowledge);
- analyzing which are the optimal methodologies to design that system (evaluate and create the procedural knowledge).

Being basic, the proposed course is not enough to encourage a metacognitive knowledge about the IoT.

**Table. 1.** Taxonomy table about IoT notions. The knowledge dimension is the horizontal axis of the table and cognitive process dimension is the vertical one.

IoT notions		A	B	C	D
		Factual knowledge	Conceptual knowledge	Procedural knowledge	Metacognitive knowledge
1	Remember	✓			
2	Understand		✓	✓	
3	Apply	✓			
4	Analyze		✓		
5	Evaluate		✓		
6	Create		✓	✓	

### 3.2 The Cyber-Physical System behind a course

The course's CPS refers to all those cyber-physical sub-systems that can work in a proactive manner and make up the entire ecosystem created by the course conduct. In [16], these components initiate collaborative actions and dynamically interact with each other to achieve both local and global goals along the three basic collaborative axes: enterprise, value chain, and lifecycle axes. We want to use the same approach but applied to the process of providing an educational service, where the three axes can be explained as follows:

- enterprise (school), that represents the entity responsible for the quality of the course, or of the service;
- value chain, that refers specifically to the delivery of the course;
- lifecycle, that refers to the design, the management and the post-service support provided by professors and tutors of the enterprise.

From the level of the physical resources up to the higher levels of the course information system, the process of course delivery can be defined as in Fig. 1, i.e., an adaptation of the classic ISA-95 that formalizes how, in order to guarantee the functioning of the class system, the involved components act and react to their environment, sharing commonalities and, on the other hand, enhancing the different aspects that complement each other to form a coherent group of resources that cooperate and react to the environment.

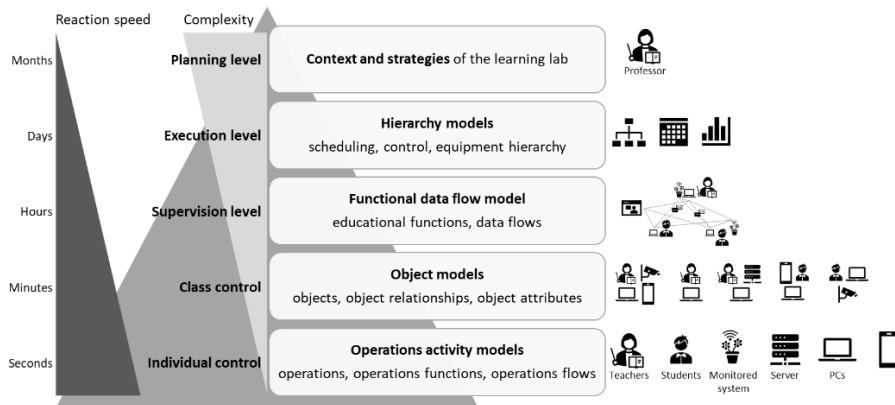


Fig. 1. CPS of the course based on ISA-95 standards.

### 3.3 Tutors and students as physical components

Tutors and students are the human components of the course CPS. They communicate through a video communication during the lecture and through a chatting app like Telegram or through email outside of class hours. Tutor and students can have in charge another physical component to be monitored with sensors, actuators and edge controlling. The student is provided with a guide that he/she can choose to follow individually to build his/her own monitored subsystem, otherwise he/she can decide to perform the lab activities using the teacher's subsystem. So, such monitored system is designed to be lightweight, inexpensive and easily assembled by students and tutors who do not

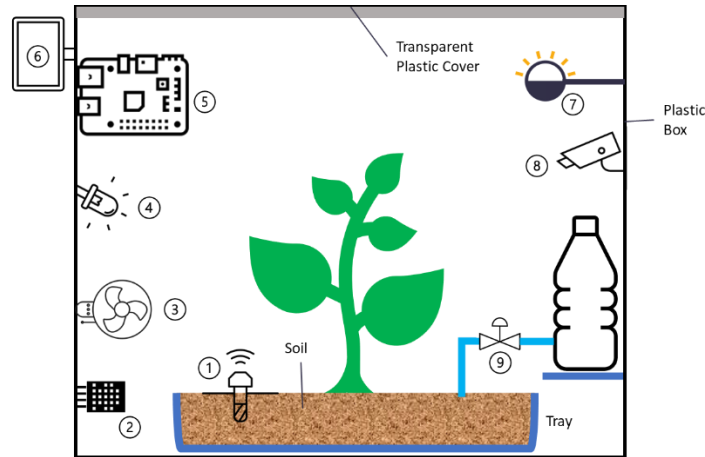


have in-depth knowledge in IoT and in particular in electronics. It is recommended to employ at least two teachers in parallel, one with more experience more dedicated to interacting with the whole class and one dedicated more to monitoring the operation of the system and tutoring individual students who report problems, so as to better manage the class, whether it is fully remote or hybrid (part in-person and part remote). These teachers ensure the success of the course for class sizes up to 150 students, who can also be organized into groups for hands-on activities without having to make changes to the course structure.

### **3.4 Monitored subsystems and devices**

The main constrain for such CPS is the inability to develop in a manufacturing environment, especially in the case of remote learning. For this reason, it was decided to define a CPS whose main component is a monitoring and management system for a domestic vegetable, i.e., a system that is relatively portable and allows students to develop all components. The agricultural sector, although different, maintains all the characteristics and difficulties of the manufacturing one: in fact, it is necessary to receive information in real time on the plant to know its status, it is essential to know how to use this information to support decisions or to automate them, it is useful to automate the actions exercisable on the plant in order to be able to act remotely, and, finally, the entire IoT infrastructure becomes essential to enable the activities described.

A plant monitoring system has been designed on the concepts of CPS and implemented under the framework of IoT. The system consists of a small vegetable that grows in a tray filled with soil. The growth environment of the plant is isolated from the outside world by placing the plant in a plastic insulated box, this is shown in Fig. 2 below. The objective of the monitoring and control system is to ensure proper growth parameters for the plant within the environment and to ensure real time monitoring, control, and transmission. This is achieved by utilizing various sensors and actuators and communication protocols. The system consists of the following elements (numbered in Fig. 1): (1) soil moisture sensor, (2) temperature and humidity sensor, (3) fan, (4) Light Emitting Diode (LED) strip, (5) Raspberry Pi, (6) LCD display, (7) light intensity (lux) sensor, (8) camera, and (9) solenoid valve.



**Fig. 2.** Scheme of the monitored system (vegetable environment) with all the devices.

With the above-mentioned components, the vegetable box performs different functions that are explained above.

- a) **Plant irrigation:** plants require a defined soil humidity to prosper, soil moisture is measured using the soil moisture sensor (hygrometer), this reading is sent to the raspberry pi which then determines whether the plant requires watering or not. If yes it issues a command to the solenoid valve to open and water the plant, this way soil moisture is maintained at an optimized level.
- b) **Plant Lighting:** the intensity of light falling on the plant is detected via the lux sensor, similar to the irrigation, the reading is sent to the raspberry pi which in turn triggers a LED, the brightness of the LED depends on the incident light falling on the plant.
- c) **Temperature control:** by measuring the internal temperature of the box, the system turns on a fan when the temperature exceeds a specific value.
- d) **Growth monitoring:** a camera monitors the plant and sends images to the Raspberry pi at specific intervals, these images are analyzed by the pi (by means of an image processing algorithm), the system is then able to determine the growth rate of the plant.
- e) **Transmission of real time data:** environment parameters acquired by the sensors are transmitted in real time to an MQTT broker, the published data can then be accessed by anyone who subscribes to the specific topics containing the data. This allows the tutors to monitor the various boxes of each student and also allows the student to monitor his own box remotely.
- f) **Storage of data in DB:** since some analysis will be performed by the students in the various course activities, the data must be available in a DB where the students can access the data performed the required analysis.
- g) **User Interface:** the box provides two interfaces for user interaction, a local one via the LCD display on board the box and a web-based Dashboard with

sensor readings and the result of the student analysis of the data in the form of various graphs, charts and text fields.

### **3.5 Design considerations**

Several aspects were taken into consideration during the development of the vegetable box, and they stem from the fact that students can develop this system in their own homes, and it is necessary to consider that students do not have a proper laboratory setup at their dispense.

The first and most important of these aspects is safety. This includes protection from electrical components and labor-intensive work that can lead to injury without proper training (e.g., cutting, drilling, or welding). For this reason, all devices in the system have been selected to be low-power and low-voltage (5v), so, for example, the pump for irrigating the plant is limited to 5v electric valve. Furthermore, plastic elements construct most of the physical structure of the box, this improves insulation and minimizes the possibility of electrical faults due to shorts or bad insulation.

The second consideration is to make configuration and installation easy, as all students should be able to do this on their own. This has been made possible primarily using two technologies: Raspberry Pi, which is a fairly simple device for technical education students to work with, and Node-red, which is a drag and drop programming environment chosen for its simplicity that allows the student to focus on system logic rather than syntax study, debugging, and syntax correction.

Another aspect that was considered is the overall power consumption of the system. The design of the approach, in fact, has considered the minimization of power consumption in order to build a system that does not significantly affect the electricity bill of the house, so all components of the system are on a small scale, where the Raspberry Pi 3-B is the most energy-consuming with a rating of about 3.7 watts with the CPU stressed to the maximum.

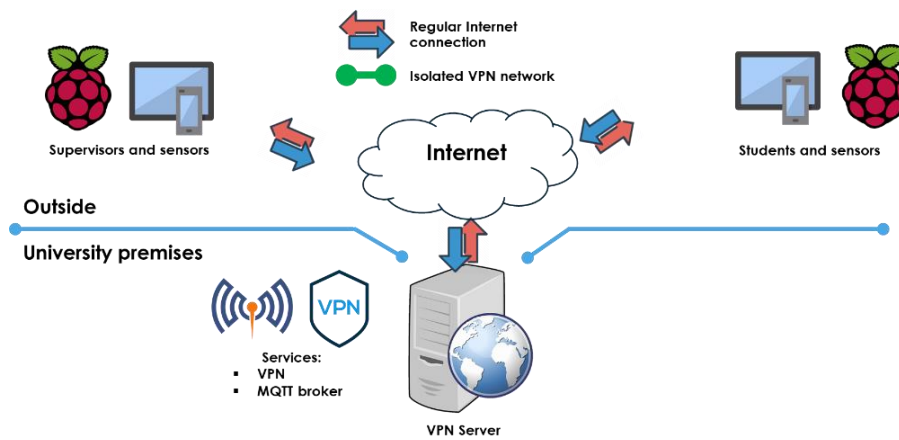
The final consideration is component availability: since students will be developing the system box in their homes, the components that make up the system should be available to them wherever they are, as, due to the Covid pandemic<sup>19</sup>, students can take the course from anywhere in the world. Consequently, the authors carefully chose components that are commonly used and found in many electronics markets.

### **3.6 Network**

The experience of the COVID-19 pandemic has shown how allowing work or training to be done remotely can protect human health. In the future, it is highly likely that much more innovation will be required to remotely deploy the majority of human activities to ensure the survival of humankind. During the spring semester for AY2019/2020, in order to mitigate the limitations imposed by the Covid-19 pandemic and the provision of seamless teaching activities for the course “Strumenti dell'Ingegneria per l'industria 4.0”, the research team, decided to run the entire lab activity via a network infrastructure. The experience of the distance activities faced with the students opened experimental opportunities to be able to define, develop and test the network architecture to be used later for more complex lab activities involving entire production

lines. The IT system behind the course is very simple in order to guarantee an easy replication of the system. Its main components are the server hosting the VPN, the laptops of the students and tutors also used as small servers, a software tool for the creation of dashboards, a development tool to create the IoT platform of the course, a platform for e-learning, and, finally, a platform for chatting outside the course hours.

The architectural design has been organized in two levels: (1) collaborative level, which consists in the definition and testing of the remote cooperation between students and teachers, (2) network level, where the network of the polytechnic of turin, the VPN and the corresponding services have been tested.



**Fig. 3.** VPN network logical topology.

Fig. 3 illustrates the logic behind the topology of the network architecture organized to conduct the course. At the top left of the figure, workstations and IoT devices are depicted. These devices were physically placed in the professors' homes. On the top right, the laptops, PCs, and any workstations located in the students' homes are illustrated. Regarding connectivity, regular internet connections (fixed and mobile broadband) and virtual private connections were established. The red and blue arrows show the regular internet connections, while the green line with circular endpoints refers to the VPN network. In the lower part of the figure, it is shown the on-premises server located in the university spaces where the core VPN network has been set up. In addition to the VPN service, the server also runs the MQTT broker service. Professors and students, via the broker, publish and subscribe to sensor data. In addition to this, professors are able to monitor student Node-Red dashboards to track student activity and help them in developing node flows. All MQTT traffic exchange between professors and students is encrypted using IPsec protocol.

The VPN network, therefore, is able to provide remote lab activity by providing direct connectivity between teachers' PCs, sensors, and students' PC/Mobile devices over the Internet, as all these devices are present in the same local area network. Sitting at home, students can interact with data from sensors installed in teachers' homes. Since Politecnico di Torino is part of the Microsoft Campus Licensing program, the VPN

network was configured to use the IPsec tunnel over the Internet, using the routing and remote access service of the Windows Server 2019 virtual machine. Professors' and students' credentials are registered in the system, so only authorized users were able to use the VPN network.

This remote teaching experience allowed to introduce and test the basic IT tools, such as VPN, necessary for the purposes of remote labs such as the one proposed in this work. Looking forward, the research team aims to replicate this experience by expanding the technological experience lived by the students. A future goal of the research team is to integrate the VPN service with the account management services on the Politecnico di Torino platform, in order to provide a better experience for professors and students. In this way, professors and students can use the same account data used for the different online services offered by the university, such as teaching load management, email, licensing and everything else.

## 4 Case study

The third edition of the IoT lab provided by the authors of the paper is considered as a case study and refers to a class of about 30 students attending an Italian first-level master's degree program, i.e., a master's degree program accessible to bachelor's degree graduates. The general topic of the master's degree concerns methods and technologies for business management, and the presented lab must turn out to be a 12-hour hands-on experience whose first purpose is to convey the concepts behind the design and development of an IoT platform for monitoring and controlling generic business resources.

### 4.1 Technological requirements

We are talking about technologies that abilities an IoT lab, so IoT is the system not an involved technology. The required technologies are listed in **Table 2** and they are divided into three groups: devices, network, and applications (app).

**Table 2.** Technologies required for the IoT lab divided into three categories: devices, network, and applications (app).

Component	Type	Description and functionality
Raspberry Pi	Device	Single board micro computer running on open-source software that contains an I/O terminal to allow the connection of sensors, actuators and other peripherals. Main controller of the system: receiving all sensor data, performing data processing and transmission, and controlling the actuators in the system.
Humidity sensor	Device	The humidity sensor is used to measure the humidity of the soil and/or air.
Thermometer	Device	It is used to measure the temperature inside the plant box.
Light sensor		It is used to measure the brightness level inside the plant box.

Temperature controller	Device	It is used to increase or dominate the temperature according to the needs of the plant.
Irrigator		It is an on/off actuator capable of irrigating the pot with constant flow or not.
Server	Device	The first purpose of the server is to host the VPN to allow faculty and students to connect to it.
PC	Device	They are used as e-learning platform and as server to run the Node-RED flows.
MQTT protocol	Network	Lightweight publish-subscribe network protocol that transports messages between devices. Data exchange between sensors and data processing stations.
VPN	Network	Secure and isolated network topology over existing untrusted public network (internet, mobile broadband). Provision of seamless connectivity between actors (teachers and students).
Node-RED	Software	Block flow (node) based development tool for visual programming that provides web browser-based flow editor to create JavaScript functions.
PostgreSQL	Software	Object-oriented DBMS released under a free license and it is used to store data provided by sensors.
Telegram	Software	Telegram is a free cloud-based instant messaging and broadcasting service.

Regarding the secure messaging app Telegram, it is important to reiterate that it is an encrypted communication tool for hundreds of millions of users worldwide. Telegram bots are small programs that can insert themselves into Telegram chats or public channels and perform a specific function. Bots are essentially automated Telegram accounts, so they can simply be added to chats and channels. The research done by [17] points out that the function of adding a bot does not incorporate the encryption algorithm that Telegram uses to protect its chats. As a result, adding a bot to a chat or channel undermines its security, potentially making it easier for a third party to intercept messages. The fact remains that this alleged flaw in no way undermines the security of the lab's performance, but it is a consideration that every Telegram user should consider.

#### 4.2 Classroom experience description

The proposed workshop will be enjoyed by students in 2021 but this work is the latest version of a series of educational activities proposed over the years even during the quarantine period. The teachers involved in the course are two: the associate professor who is responsible for the introduction to the course and the explanation of the industrial context, while the PhD student with already years of experience in teaching accompanies the development of the components of the system proposed to students. In carrying out the practical activities, it is necessary the presence of another tutor who helps in following the single elements of the class and controls that the whole system

works, this to avoid that the teacher wastes time in the settings lowering the intensity of the course.

The **Table 3** describes in detail the idea about the course program. The course is divided into lessons of one hour except for the introductory and concluding lessons whose duration depends on the level of detail with which the teacher wants to introduce the industrial context and understand the notional background acquired by the students at the end of the course. The method of student evaluation is based on 8 tests during the whole course and these tests provide a maximum of 3 points based on the performance of the student who at the end of the course will therefore have a maximum mark equal to 21. In addition to the final evaluation, this methodology allows to constantly monitor the interest, the attention, and the involvement of the class.

To interact with students, tutors use an e-learning platform during class, email for official communications, and Telegram during any time. Telegram, in addition to being a monitoring system interface, allows for polling teacher-student communication and promotes the class communication. In fact, the student through the chat can confront with the teacher and other students to solve some doubts and can provide the teacher, when required and not, real-time feedbacks on the course using hashtags. The hashtags chosen by the teachers will help them to easily access these feedbacks to improve the current course, but even more so the future editions.

In order to allow students to build their own plant box, tutors make materials available at the beginning of the course (video lectures or instruction manuals) or by giving consultations to interested students only. All students are given the opportunity to interact with the teacher's system but are strongly recommended to develop their own.

**Table 3.** Program for the IoT lab divided in lessons with the Measurable Students Evaluations (MStE) performed by tutors, that are: Survey (S), written Free Feedbacks (FF) and Exam (E).

#	Lesson title	Lesson description	MStE	Evaluation description
1	Introduction to Industry 4.0	Class presentation, introduction to the course, contextualization in the manufacturing sector, and discussion of the new paradigms of Industry 4.0	S	Survey
2	The lab	Explanation of lab activities and first settings	FF	
3	Development of an IoT platform	Design an IoT platform, introduction to JavaScript, Node JS and Node-red and first exercises.	E1	Send email with Node-RED and other exercises
4	Human Machine Integration (Interface)	Designing of the user experience and developing of the dashboard	E2	GUI check
5	System monitoring	Description of the monitored system (the guide to how build it is	E3	Send .txt with recorded data

		in e-learning), how interacting with sensors and actuators		
6	Historical data	Introduction to the DB management systems and description of how storing data with Node-RED and PostgreSQL	E4	Send email with aggregated historical data
7	Telegram API	Introduction to API, Telegram and chatbots	E5	Add the bot to the course group and the bot introduces itself to the group
8	Chat as HMI tool	Use the bot to interact with systems under analysis	E6	First automatic interaction of the student bot with the tutors
9	Weather data with API	Storing data about weather using free API [18]	E7	The student bot activities include weather data
10	Game	Understand better the importance to be online and so interact in real-time	FF	
11	Advanced analytics	Concepts of artificial intelligence, machine learning, sentiment analysis, audio processing and image processing	FF	
12	Final class evaluation	Course conclusion, class reflections, and final teacher evaluation	E8	Final test

## 5 Conclusion and future works

This paper exposes the first results obtained from the design and formalization of a basic training course on IoT systems that is fully remotely deliverable. The theoretical contents of the course and the narrative of the same concern the industrial sector in the era of the fourth revolution, i.e., the digital one, and in this context, when digitalization is accelerated by the advent of the pandemic due to SARS-CoV-2, the course object of this work can be taught all remotely. The objective of the course is to provide the student with basics of telecommunications engineering, insights regarding the manufacturing sector in the era of Industry 4.0 and support to develop a prototype system for monitoring and control of a resource (plant) and a process (growth of the same) through communication protocols MQTT, Raspberry Pi and JavaScript programming interfaced by Node-RED.

This work is a first result of a research path to develop a remote research effort to develop a remote manufacturing experience. The research team is building a manufacturing line that includes additive and subtractive processes and can allow students to monitor and control the production of simple products. As future developments to this work, the team is currently testing these methodologies in a training course to gather quantitative results on the students' learning process.



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