Learning-IoT: Methodological Framework for Remote Robotics Teaching

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Abstract* — Much has been discussed recently about the implications and strategies adopted by higher education institutions concerning the realization of online practical classes due to COVID-19. Some teaching institutions used virtual meetings to reorganize the lesson plan to continue teaching and assessing the students due to the suspension of face-to-face classes due to this epidemic. Although the most adopted strategy among the courses has been direct communication between students and professors through e-mail, telephone, social networks, and message apps, education lives in a time when transitions seem to occur much faster than in recent decades. For example, online engineering courses, specifically robotics, face difficulty implementing practical activities online because the educational tools available remotely are scarce or very expensive, thus becoming an obstacle to circumvent. Given this, this article presents a methodological strategy for the teaching-learning practices of engineering through Learning-IoT. This is a methodology for teaching robotics using the Internet of Industrial Things (IIoT) concepts. It enables the connection of the student to a Physical Objects Framework proposed in practical online activities and by the project method responsible for stimulating critical thinking. Thus, the initial ergonomic interface test experiments and usability of the proposed methodology demonstrated in the experiments in online practical classes that memorization and decision-making fit new possibilities or functionalities.

***Keywords*— Remote learning, cloud robotics, embedded systems, design method, distant laboratories framework.**

I. Introduction

Higher education institutions have adopted various strategies to prevent student dropout due to COVID-19. This perception confirmed the findings of many authors [1, 2, 3, 4]. Although the most adopted method among the courses has been remote teaching activities to reduce the losses in their students' learning, education is living in a time when the evolution of universities and educator digital competence (EDC) implies changes in university pedagogy, management, and equipment [5].

There is little availability of equipment or a teacher to monitor the practices necessary for student learning in educational institutions. This is not a particular problem in Brazil but a situation seen in many other countries [6]. Currently, remote laboratories can be used to reduce this problem. For example, professors from the universities of Bulgaria and Portugal related various actions to adapt their electrical engineering classes to this new reality. They adopted different teaching materials to face the difficulties of practical lessons during the pandemic because the educational tools available for remote laboratory experiments are scarce or expensive, thus becoming an obstacle to circumventing [7, 8, 9]. Similar problems occurred in engineering courses, specifically in teaching embedded systems for the robotics course. Remotely embedding the code in the microcontroller becomes an important practical activity because it aims at the control actuators and sensors skills necessary for educated professionals. This is a relevant functional activity in the new electrical engineering, mechatronics, robotics, and computing curricula worldwide. Moreover, most of the tools used in the educational environment were not available in the students' homes, and adopting a more practical approach to teaching motivates students in technological learning [10].

Engineering students must solve practical problems close to the real world, but due to the COVID-19 pandemic, face-to-face access to teaching labs was compromised. Therefore, it is necessary to seek virtual ways to teach the concepts of these technologies to students. Our research group has developed industrial automation applications [11] and home automation systems [12, 13]. In this sense, a series of tools and technologies were used to teach the digital twin concept at a distance to undergraduate students in 2020.

Starting from this perspective, this paper presents a methodological strategy for the teaching-learning practices of engineering through a framework named Learning-IoT. This methodology for remote robotics teaching uses the Industrial Internet of Things (IIoT) concepts. The IIoT refers to sensors, instruments, and other devices interconnected in a network with industrial computer applications, including manufacturing and energy management [14]. This connectivity will allow the student to collect, exchange and analyze data in the object dashboard (sensors, actuators, manipulators, gears, etc.) proposed in this project.

At the same time, the didactic method used was the project method, which aims to transform students' attitudes during teaching. The students must become active beings who conceive, prepare, and conduct their work. The teachers' task consists of guiding them, generating valuable ideas, and helping them when necessary [15]. On the one hand, to minimize the described obstacles and, on the other hand, to motivate students at home, the Learning-IoT is already being used in remote and face-to-face classes of engineering courses at our university. The courses are primarily four credits, which means 60 hours per semester, and the specific learning objectives of this course are proficiency in embedded systems. This methodology is also expected to minimize the dropout rate in distance education. Thus, the paper is divided into two parts, one presenting the Learning-IoT structure intended to help teachers and students in the digital teaching-learning process. The other describes the motivational didactics of remote practices.

The proposed Learning-IoT tries to maximize practical activities in the remote learning environment. This approach unfolds in two lines of reasoning. Develop a user-friendly structure containing the subject matter and practical remote activities to be implemented using the IIoT technology. In this context, students and teachers were added to a platform with four service components: object panel, server, communication, and Learning-IoT. We adopted components that can be replaced and updated independently [16]. In fact, by interacting with the actual object through its components, students can improve their cognition and minimize the problem of practical classes in remote teaching.

A second concern is how to motivate students through the project method. This approach arose from the need to insert interactive procedures for students and educators to establish the understanding and interpretation of information for specific issues [15]. In this phase, a specific remote activity is proposed for the students. They will develop a source code in the cloud platform, simulate and evaluate it, and finalize the job by uploading their solution to the university laboratory's microcontroller board.

In summary, the main goal of this paper is to present a framework called the Learning-IoT that was developed to minimize the lack of practical classes in remote robotics teaching, more specifically, in the disciplines of software programming language for embedded systems. This article is structured as follows: Section II contains the related work and specifies its motivation; Section III details the proposal; Section IV evaluates the results obtained; and Section V presents some final considerations and future work.

II. Related Work and Motivation

In March 2020, several educational institutions and educators were forced to integrate their teaching into remote environments [17, 18]. Remote education can be characterized by creating a climate that unifies students, teachers, and management teams in virtual environments. In addition, it is possible to enable live classes, recording, interactive chats, editing of documents, and organization of materials by classes, with those activities being performed in real-time or offline by the teaching staff of each subject. However, some authors report that the migration from face-to-face to online teaching caused the redefinition of the educational methodologies. In many cases, they sent the student a kit of prototyping material aiming at better strategies in the online teaching-learning practical staff, which involved the students synchronously [19, 20, 21].

The authors in [22] warn that tools can be designed with a focus on the obstacles encountered in remote teaching. Incorporating such a tool into undergraduate curricula will undoubtedly help teachers prepare better remote classes.

In [23], Vanessa Ripoll and her coauthors propose a sequence of practical activities through collaborative learning and active student participation to replace the traditional mid-year exam. Their approach integrated the collaborative method into practical modules in engineering courses. The learning goals were achieved using new activities such as abstracting to extract relevant information from an empirical case using appropriate mathematical methods. They could derive information from a practical issue for applying biochemical engineering principles and discussions among peers about the results and repercussions of a practical case.

Meanwhile, Marie Debacq and colleagues report that the experiments conducted on remote teaching during COVID-19 extracted exciting lessons for the future and can be seen as a great incentive to further develop hybrid teaching approaches in food engineering. Moreover, the educational resources and practices implemented in these exceptional circumstances are an opportunity to create new teaching methods [24].

For researchers from Mexico's Autonomous Metropolitan University (UAM), the individual pandemic isolation and the necessary social distancing left two legacies. First, online education is here to stay, and the second was that the university community joined forces, overcoming obstacles, and sharing knowledge to win the inertia of technology-mediated education. Thus, remote education has proven to be an efficient means for cases of forced social distance. However, the developed model can still be improved to allow its application in practical terms [25, 26].

Thus, the main difference in this project is the way to transfer the students' source code from point A (student's home) to point B (robotic laboratory) employing LoRaWAN and Machine to Machine (M2M) technology. Thus, this method can send tiny data packets reliably. The IoT aims to connect smart devices and the internet network to store data, monitor physical space, control the environment, and support decision-making [27].

TABLE I. METHODS

Ref. #	Remote methods			
	Specific learning method	***Comparison Table***		
		Theory	***Practice***	***Technology LoRaWan/M2M***
[03]	ERL	Yes	No	No
[18]	The academically productive conversation (APT)	Yes	No	No
[21]	Tangible and embodied interaction (TEI)	Yes	No	No
[29]	Digital Twins	Yes	Yes	No
Ourself	Learning-IoT	Yes	Yes	Yes

M2M, on the other hand, was used to remotely monitor, collect, analyze and adjust a sensor/actuator through Message Queuing Telemetry Transport (MQTT - light messaging protocol for sensors) protocols or Wi-Fi 6 internet access connection [28]. In summary, Table 1 presents the remote methods explicitly applied in several cases aiming at the engineering teaching-learning process.

This article has two main objectives based on this context and is motivated by these studies. The first is to develop the Learning-IoT method to be used in the remote practice of robotics courses. The second objective is to create scenarios that would implement a motivational didactic, where the method could be used as a practical tool common to all participants.

III. Description of the Developed Learning-IoT

The proposed model is recommended to minimize the difficulty of practical experimentation in the remote learning environment. The focus of the Learning-IoT is to grant student interaction in practical activities by remote means. The framework shares two cloud platforms. The first unifies students/teachers, and the second communicates with the developed component named in this project as "Leaning-IoT" to implement the students` remote practical activities [30, 31]. In addition, freeware software was used to assist in the remote communication of the classes [32,33].

The project methodology intends to keep students immersed in remote teaching activities. Furthermore, a hybrid approach containing the characteristics of techniques reported in the literature was elaborated [3, 5, 7, 8]. These techniques motivate students, allow the socialization of experiences, promote better understanding, and assist in developing skills [22, 23]. This method is intended for a group of students whose behavior throughout the remote classes is observed, measured, and evaluated. The following sections will expose details of the developed experiment and criticisms about the obtained results.

A. Learning-IoT Architecture

Fig. 1 shows the proposed stack layers containing the five main components of the proposed system.

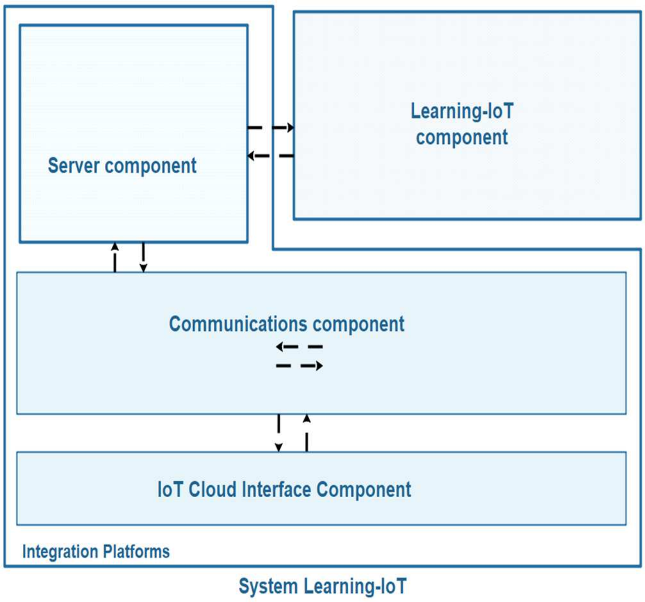

Fig. 1: Learning-IoT – System Components

The IoT Cloud Component is the interface created in the cloud for students to implement the source code based on the planned activities and evaluate them in the Learning-IoT component. The Learning-IoT is a hardware board developed to control sensors and actuators and is connected to the server component. The Communication Component manages the Learning-IoT and establishes a remote connection with the students' and teachers' devices. The AnyDesk tool establishes a secure connection between the student or teacher and the internet [33]. The last component, Integration Platforms, is the integrative platform responsible for wrapping all the other components and establishing communication with human peers by employing video conferencing.

Particular attention must be given to the Learning IoT component. Fig. 2 presents the collection of small autonomous services that implement this component's main functionalities. Each service is independent and implements a single functionality in the Learning-IoT system.

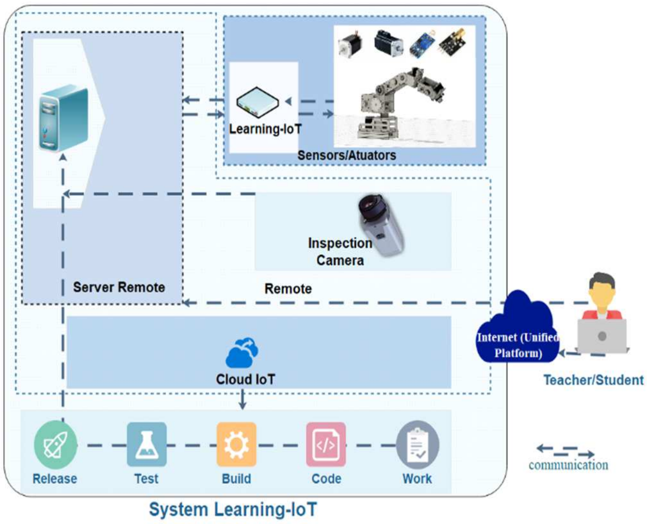

Fig. 2: Sistema Learning-IoT - Microservices

- The remote server runs the Windows Server platform and hosts the remote connection and cloud IoT interface services.
- Learning-IoT - consists of two microcontrollers. The first integrates WIFI with the IoT gateway protocol. The second performs the control service of the I/O ports interconnected to the actuators, sensors, and the robot. The learning-IoT is connected to the remote server via serial ports.
- The Cloud IoT Interface service created in the cloud allows students to develop, test, and send their code to the Learning-IoT (object panel).
- Teacher/Student runs the video conferencing platform and integrates the cloud IoT interface platform remotely or locally via a remote server.
- The inspection camera is responsible for identifying whether the conditions of task execution conform to the standard set by the Cloud IoT interface and is connected to the remote server.
- Internet (Unified Platform) - video conferencing platform responsible for guaranteeing communication with the remote server, students, and teachers.

After modeling the architecture, an environment with the Learning-IoT system was built in the robotics laboratory. Fig. 3 highlights the main components and their relationships in this physical environment. They are the server component with one connected inspection camera and the Learning-IoT component with the sensors. The system and the students are connected to the server. All these components have already been conceptualized earlier.

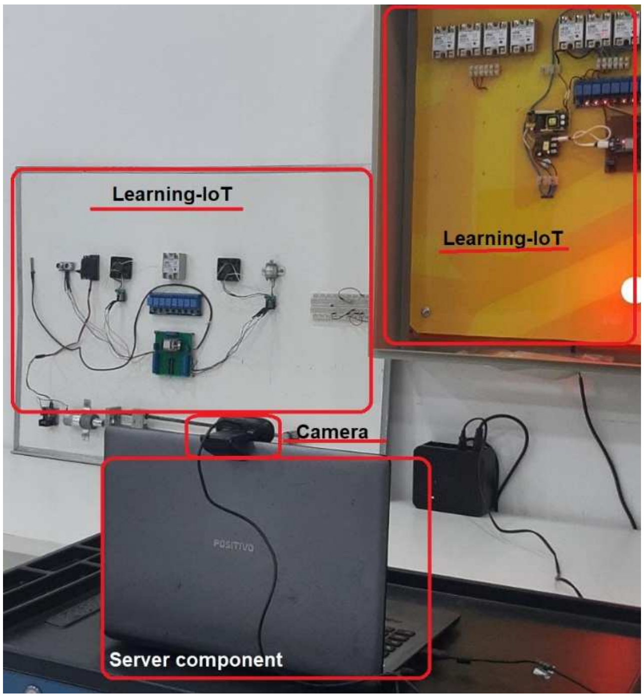

Fig. 3: Learning-IoT - Ambient

Fig. 4 shows the integrator platform for remote data. The Microsoft Teams platform was used for this scenario, but other platforms, such as Google Meet or Zoom, can be used [30, 34, 35]. Inside the unifying platform are IoT cloud interface screens where the student-run develops the algorithms. The Learning-IoT, with its acting components, lies next to it. The courseware addresses the necessary subject matter for first-year students. Thus, it is not enough to solve an algorithm problem in the platform, and the central objective is to execute these algorithms in the Learning-IoT.

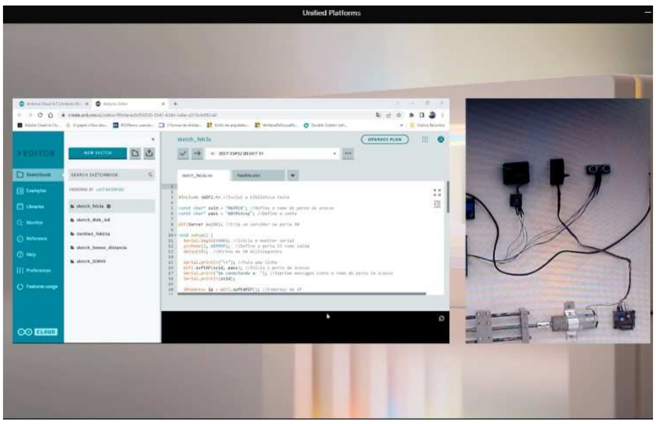

Fig. 4: Integration Platforms (Cloud IoT Interface)

Fig. 5 shows the Cloud IoT Interface editor area. It has a sketchbook tab for tying up the students' last practical exercises. There are also examples of tabs for the students to have an initial reference in the activities. The library tab assists them in communicating with the Leaning-IoT. There is also the serial port monitor to verify communication with the Learning-IoT and the reference tab to assist the students in constructing variables, functions, and structures. In addition, the help tab presents several tutorials.

A first experimental attempt was made using the C programming language course with applications in robotics. Fig. 6 shows the screen of the unifying platform, and it contains the screens of the Cloud IoT Interface, the Learning-IoT, students/teachers, and activities to implement. This figure summarizes the front end of the Learning-IoT system. For students to have shared access to the remote server to control the Learning-IoT, they must install the AnyDesk software, and the teacher must pass the security access code to their students.

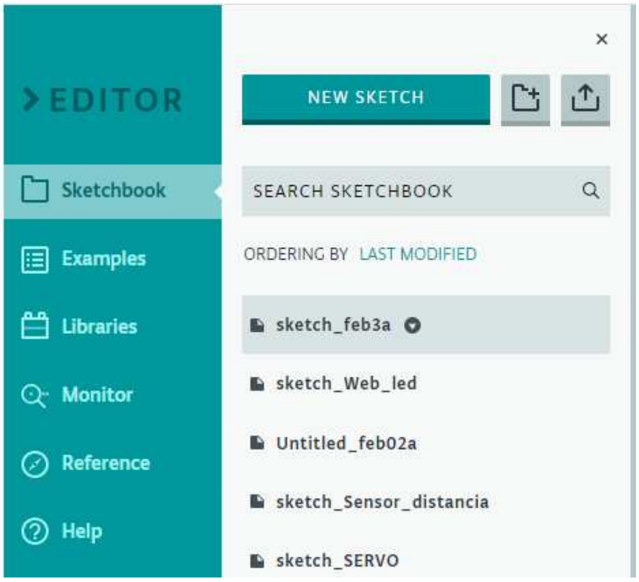

Fig. 5: Cloud IoT Interface - Editor

With the environment configured, teachers are free to insert the planned activities, and students must complete their tasks accordingly. Students can use predefined commands or program them directly in C. The example palette contains several templates for the robot commands. After creating a project, students can execute an actuation and sensing command remotely, and code execution takes place in the Learning-IoT system installed in the lab. The camera is used to give feedback about the proper code implementation.

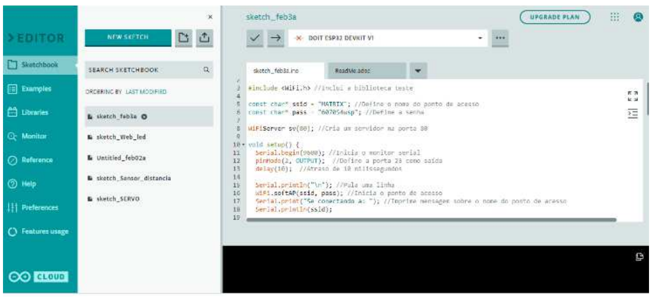

Fig. 6: Integration platforms - Perspective of students

Students should not worry about their remote connection to the Learning-IoT panel. They should only concentrate on solving the algorithms determined by the teacher. A set of guiding libraries, which reuse software components from Learning-IoT (controllers, sensors, actuators, manipulators, etc.), have been integrated into Learning-IoT. They facilitated programming in this environment.

It is worth noting that this environment is intuitive and easy to learn. For example, in the C language course, you can confirm that a C code is wrong or correct, as it will change the behavior of a desired sensor or actuator. If students need a motor to turn left or right, they will make a code to move the robot in the desired direction. If it does not execute the code in Learning-IoT, the problem will not be with the connection but with the student's code.

Furthermore, the robot that the Learning-IoT will manipulate is under development. The initial tests will be implemented with the sensors and actuators of this robot (Fig. 7). We chose to build this type of robotic arm because it is popular. Moreover, we can have complete control of the software and hardware, i.e., these three factors combined form the basis of a fantastic experience for students and provide options to correct mistakes to beginners and long-time developers. The idea is to have absolute control of the movements of this robotic arm in the remote class.

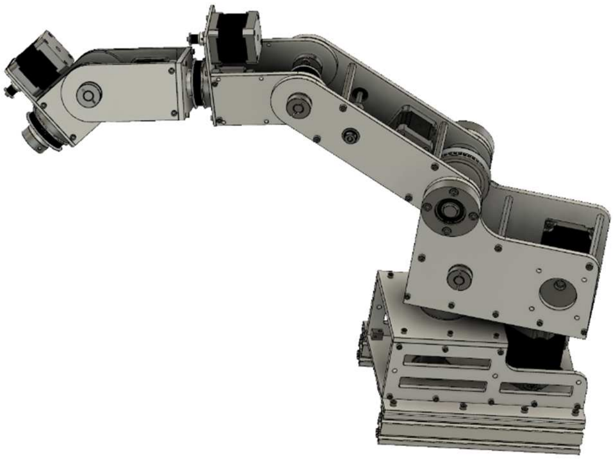

Fig. 7: Robot learning-IoT

B. Motivation - Project Methodology

The proposed methodology involves all activities (manual, intellectual, social, etc.). Every project is a problem, but not every issue is a project, and students can learn in groups or individually. The teacher must be in a structured environment with the Learning-IoT system kit. It is worth mentioning that each kit caters to five (05) students in a scalable way, and it is recommended to have two kits per class session. In addition to the kits being free of charge, they should provide students with the search for solutions to robotic problems through remote hands-on activities.

Some activities must be performed individually, but classmates can help each other. During the whole remote lesson, the lecturer is always available to help the students. Ultimately, each student must implement their code remotely so that the lecturer can assign a concept. After the definition of the Learning-IoT system, a set of theoretical assignments is proposed to each student. Thus, the proposed method adopts the following procedures:

- Selection or elaboration of problems by the teacher or by the student or teacher and student.
- Planning of all the details of the problems.
- Gathering information and selecting the material needed to conduct the various phases of the problem.
- Test execution of the tasks envisaged conducting the problem remotely.
- Presentation of the problem in class to be discussed by all participants.
- Teacher feedback on the work conducted.

These steps were set up to help students embrace the fundamental concepts of the programming language being addressed. Once the students have built the solutions to the problems, the testing phase begins. This phase is essential for them to make the learning; that is, through the mistakes, they will eliminate doubts in the algorithms, and finally, the students will remotely ship the codes to the Learning-IoT. Already, the process specifically of executing the code in the Learning-IoT system happens as follows:

- Step 1: The learner receives the problem.
- Step 2: The student creates the code.
- Step 3: The student informs the teacher that he is ready to test the code in the system.
- Step 4: The student awaits the release of the learning-IoT system by the teacher.
- Step 5: The students code on the servos and analyze the results of the execution of the actuator or robotic sensor.
- Step 6: The student receives feedback from the system and the teacher.
- Step 7: Depending on the feedback from step 6, the student returns to step 2 or goes to step 8.
- Step 8: End.

In addition to this didactic approach, you can create a set of theoretical and practical activities and distribute them among the students. They should solve the problems and present the proposed solutions to the teacher. Another way of motivating them is through competitions, where teams must develop an algorithm to complete a set of problems. The winning team will be the team with the most efficient algorithm, which meets the activity in the shortest time.

IV. Obtained Results

Two surveys were conducted to measure the impact of using the Learning-IoT system, the first aimed at the system's usability and the second at pedagogical issues. The system was evaluated utilizing the ISO 9241 Standard - Part 10 - Dialog Systems, based on the ten usability heuristics proposed by Nielsen [36]. The usability criteria presented by Nokelainen [37] were used to evaluate the methodology.

To measure student satisfaction with the Learning-IoT system and its pedagogical efficiency, a Likert scale [37] was used with a score from 1 to 5, ranging from strongly agree (5 points) to strongly disagree (1 point), as shown in Fig. 8.

Fig. 8: Lickert scale response

The first set of questions, inspired by Nielsen's method, was developed with ten students. They evaluated the tool through general usability criteria, and the results were quite promising. The weighted average was 72.0% for students motivated by the system. For partially motivated, it was 23.0%, and not motivated (5.0%). The last result was that the student would like to return to the classroom and claimed that the Learning-IoT system did not help his learning.

TABLE II. GENERAL USABILITY HEURISTICS

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Motivated	70	80	90	60	70	70	70	70	80	60
Partially Motivated	30	20	10	40	30	30	30	30	0	10
Not Motivated	0	0	0	0	0	0	0	0	20	30

TABLE III. LEGEND OF THE GENERAL USABILITY HEURISTIC

Heuristics	Question:
P1	Visibility of the current context of the system
P2	Interaction between the system and the real world
P3	User control and freedom
P4	Standards in the graphical interface
P5	Error prevention
P6	Recognition instead of memorization
P7	Flexibility and efficiency of use
P8	Minimalist aesthetic design
P9	Diagnosing and correcting errors
P10	Help and documentation information

Most students stated that the practical use of the Learning-IoT system was exciting. They reported that it was easy to understand the concepts of the C programming language, as there was an interaction between theory and practice in their abstract programs. They also stated that they "had motivations in seeing the remote interactions" with sensors and actuators of a robot. Furthermore, they reported that it was one of the reasons for keeping them motivated throughout the remote classes. An additional problem we needed to face was the intermittent lack of power or fault of the internet, which caused delays in the classes and the execution of the practical experiments.

To verify whether the system met the student's expectations in remote classes. The Likert scale was used, with scores from 1 to 5 ranging from strongly agree (5 points) to strongly disagree (1). Thus, the weighted mean (MP) of the item Strongly Agree was 76.66; therefore, it was concluded that the level of pedagogical satisfaction for the system users was equal to 76.%.

TABLE IV. HEURISTICS OF PEDAGOGICAL SATISFACTION

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1-Full Agreement	70	80	90	80	70	80	70	80	80	60
2-	10	10	5	10	20	10	20	10	20	20
3-	10	5	5	5	10	5	5	10	0	10
4-	5	5	0	5		5	5	0	0	10
5- Totally Disagree	5	0	0	0	0	0	0	0	0	0

TABLE V. HEURISTIC LEGEND OF PEDAGOGICAL SATISFACTION

Pedagogical Satisfaction (SP)	Question:
SP1	Can this material be understood and used by any student with little or no computer experience?
SP2	Was it easy to learn how to use? Did you not have to ask the teacher for help until you understood how the system worked?
SP3	Do you find that the content of this material keeps your attention?
SP4	Is it more beneficial to learn subjects with this material than in a regular classroom?
SP5	When you study with this material, do you feel you know more about some topics than others? (You learn the other issues but feel you have become an expert in some)
SP6	Is it enjoyable to use this material with another colleague on the same computer?
SP7	After you have used this material, are you told what you expect to know (or learn)? (Ex: the program says: -After this lesson you will know how to ask questions in English).
SP8	When you start using this material, is it shown why it is helpful to learn it? (The program says, -This lesson will help you make interrogative sentences).
SP9	Does this material show you how to apply the knowledge you have learned to situations in your daily life? (For example, calculating how many square feet the room in your house).
SP10	Does this material use the idea that learning by doing on your own is better? (A good amount of exercises are provided)

We could also compare grades obtained in previous semesters with those obtained in this current course and the dropout rates. Unfortunately, social distance was an obstacle in collecting the data, and it was necessary to formulate a consistent evaluation methodology. We can say that the Learning-IoT system was motivational, and the satisfaction rate of the method was positive.

V. CONCLUSION

This paper described the proposal of the Learning-IoT system, whose goal is to implement the practice in remote classes using software tools, a remote network, a robot (with its actuators and sensors), and a particular project method. The proposed methodology unifies students and teachers on a cloud IIoT platform to execute practice experimentation remotely. The proposed actions should be done in collaboration with the "man-system-robot," and each activity resulted in concepts for the student. In addition, this methodology framework can assist the lecturer in the following:

- To provide the student with an authentic situation of living and experience.
- Stimulate creative thinking.
- Develop the ability to observe to make better use of information and instruments.
- To value the need for cooperation.
- To allow students to prove their ideas by applying them.
- To stimulate initiative, self-confidence, and a sense of responsibility.

With these proposals, students could develop a code structure to control sensors and actuators remotely. Each activity generates a concept for them. In this proposal, all the participants gained ideas independent of success or failure. The proposed Learning-IoT system can be improved and adapted to distance education (DE) systems over a specific course. A positive point is the practical use of a remote connection through IIoT technology. The Internet of Things has proven to be an effective way to enhance learning. Finally, the methodology was also an interesting motivational tool for unmotivated students.

The following steps are related to the finalization of implementing a remote interface system to assist the instructor in collaborative robots in the industry. The final interface will be designed using usability concepts for education and intends to increase the benefits of the teaching-learning process. Through qualitative and quantitative evaluations, an extensive survey will seek feedback from shop floor instructors, students, and teachers. Future works include repeating the experiment with a collaborative robot, integrating a control interface for the robot, integrating other programming languages, and inserting new tools that consider web and mobile applications.

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