Hobots: A Remote Teaching Method for Collaborative Robotics Learning

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***Abstract* — This research-to-practice full paper focuses on the use of technology in education, which enables a wide variety of activities. For example, a computer with internet access allows students to read articles, make video calls, perform group work, and even take tests. In 2021, this tool was relevant to face-to-face teaching because the interruption caused by COVID-19 resulted in social distancing. In this way, remote teaching was adopted as an emergency measure in the teaching process. Although remote teaching uses technological innovation, it lacks the inclusion of educational theories and remote practices in virtual classes. Thus, this approach analyzes Lev Vygotsky's theories of learning, specifically the zone of proximal development and scaffolding, to understand the satisfaction of learning the content alone or with other people's help through the Industrial Internet of Things (IIoT) technology. It then investigated IIoT, intending to build a remote virtual environment. In this context, it was possible to develop a remote teaching method called Hobots. This remote teaching method comprises six collaborative modules (the integrating platform, interfaced, MQTT broker, communication module, server, and Robot-X) for the remote teaching of industrial robotics. In addition, the method was evaluated by ten students using the ISO 9241 - Part 10 - Dialog Systems standard, with a view to their satisfaction with using the method in the remote teaching process, and the results were admissible. Therefore, in addition to theory and simulation, the proposed method stands out for the possibility of remote implementation.**

Keywords— Mechatronic Laboratories, Remote Laboratories, Distant Learning Experiments, Online Students, Digital Twin.

I. INTRODUCTION

Using computers in teaching was initially unfeasible, as they were complicated machines to manipulate. With the rise of technology, the spread of computers in the educational environment has enabled new methodological tools, both for students in constructing their knowledge and for teachers in the teaching-learning process [1].

Currently, both face-to-face and distance learning prepare people for the job market. During the pandemic, face-to-face classes were replaced by remote learning. This emerged as an alternative to reduce the negative impacts of social distancing on the teaching and learning process.

Thus, remote learning has become a modality for teaching activities guided by technology guided by face-to-face education principles [2]. In this way, students attend classes in the same period they would be present at the educational institution, respecting the workload of each grade and pedagogical plan.

In practice, teachers and students in various locations access a virtual environment to maintain the classroom routine. This modality is designed to provide the necessary support for the learning process through technological resources. For example, video classes, tutors with a wide range of availability, live discussion forums, and virtual learning environments can be used [3].

Although remote learning has many benefits, this modality still faces several challenges, such as the lack of a digital environment based on educational theories, inadequate assessment systems, difficulties in group work interactions, and the slight inclusion of practical tools in the virtual learning environment. Similar cases have occurred in engineering courses. For example, the Industrial Robotic Process course needed to remotely embed the code in the microcontroller of the robot's control center, but this was not possible because of a lack of methodological resources. Another similar case is for activities in which the robot can move at an angle of 90° from 45°.

This activity is relevant to new electrical engineering, mechatronics, robotics, and computer science curricula worldwide [4, 5]. In addition, most of the tools used in the educational environment are not available in the students' homes, and adopting a more practical approach to teaching motivates students in technological learning. According to psychologist Lev Vygotsky, each subject acts according to what they learn in their first subjective interactions, which begin in the family and continue throughout their lives through actions and perceptions [6, 7].

Therefore, to minimize this problem of remote teaching, developing a specific method to collaborate with remote practices in the laboratories of universities, schools, and industries is necessary. For example, face-to-face teaching has had to adapt throughout its history to improve the teaching-learning process.

From this perspective, how can we develop a method to collaborate with practical experiments in the remote teaching model? Therefore, a remote teaching method called "Hobots" is proposed here to collaborate with the student in the remote practical activity of the robotic industrial process subject. This methodology uses scaffolding theory and the Industrial Internet of Things (IIoT). The IIoT refers to sensors, instruments, and other devices networked with industrial applications, including factories and energy management [8, 9, 10]. This connectivity allows students to collect, exchange, and analyze data via this methodology.

Thus, scaffolding theory will be the basis for developing the Hobots method, as it is a teaching method that helps students understand content through the technological resources used in the learning process [11]. In addition, scaffolding refers to the structure other students provide while learning a skill. This skill usually follows a series of steps called "scaffolding" and provides a foundation on which the student develops their skills [12].

In this context, there are three zones on the scaffolding: the Zone Out of Reach (ZFA), the Zone of Proximal Development (ZDP), and the Zone of Actual Development (ZDR). Therefore, the individual may be in a development zone but distinct from mental functions on the basis of their skill set.

In the ZFA, the student cannot conduct the activities with the teacher's help because the student's current skill set does not allow them to do so, even with the help of a specialist [13]. According to Vygotsky's development theory, specialists can lower the difficulty level and look for more suitable tasks according to the student's mental development and skill level [12].

In the PDZ, the student can conduct activities with the teacher's assistance; similarly, the student has almost mastered a set of skills needed to complete a task but still requires the supervision of a teacher. In this zone, Vygotsky believed that the specialist could apply different techniques to enable the student to better understand the skills and concepts needed to perform a task without assistance [14, 15].

In the DRZ, the student can conduct activities without the teacher. Likewise, the student masters the skills to complete a task independently [13]. The assistance of a specialist is not necessary because, upon reaching this new step, the teacher can present new materials to the students in the ZDR to find new skills with the help of scaffolding theory [11, 12, 13, 14, 15].

According to Lev Vygotsky's theory of development, when a student is in Z.D.P., an experienced person (teacher or experienced student) can provide suitable scaffolding to help them realize a new skill. Thus, when instructing students, teachers can use the proposed method to guide them through each lesson. Hobots are able to collaborate with students in regard to understanding concepts and allowing teachers to focus on specific areas of instruction rather than having to cover every topic.

In summary, the main aim of this article is to propose a method for assisting in the remote teaching of robotics. To implement this method, it will be necessary to adapt new guidelines to meet the needs of higher education students via technological resources. This article is structured as follows: Section II contains the related work and 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

Industry 5.0, also known as the Fifth Industrial Revolution, is a new industry phase in which humans collaborate with robots called Cobots [16, 17]. In this context, the quality of vocational training in remote learning is being questioned: Are institutions prepared to receive Industry 5.0 and, in the future, 6.0? Researchers such as Lev Vygotsky have emphasized students' obligation in society, i.e., the individual who instructs has the responsibility to organize the social and educational environment in such a way as to deliberately contribute to the development process of the learner [11, 15].

In addition, some authors report that the shift from face-to-face teaching to remote teaching has redefined educational methodologies [18, 19]. For example, researchers in [20] reported that Industry 5.0 must establish the creativity of human experts in collaboration with intelligent machines and production systems to achieve efficient solutions on the shop floor. However, the number of physical learning environments with the skills required by Industry 5.0 is still limited.

Researchers [21] introduced a new robotic teleoperation platform that allows remote access to industrial robotics laboratories to train engineering students. The teleoperation platform has shown excellent results for learning robotics remotely, regardless of time and place. The platform enables teleoperation, remote control, and near real-time controlled robot monitoring. However, they warned that it is necessary to evaluate and analyze the details of the proposed technology in various sectors of the teaching-learning process and industry.

The authors of [22] reported on the technical challenges in managing the infrastructure of a robotic system. They presented an approach for the remote operation of robotic manipulators. To this end, an open-access web platform for robotic remote control has been developed. This platform contributes to research and training in robotic systems between research centers. In addition, students and researchers can use this educational tool, which differs from traditional robotic simulators, through a virtual experience that connects real manipulators worldwide via the internet.

The authors of [23] proposed a design for a modular robotic skin capable of simultaneously detecting the magnitude and location of a contact force. Each skin module requires three degrees of freedom in detection to estimate the horizontal and vertical locations of the contact force and its magnitude. A customized triangular beam structure under the skin cover makes the proposed skin force detection method possible. This enables tasks to be performed with a high degree of complexity.

The related works do not address the problems involved in this proposal simultaneously, such as the lack of practical activities and the lack of learning theory. However, research has focused on promoting architecture design with the essential characteristics of remote teaching methods. Table I below shows the main differences between the works related to this research proposal.

TABLE I: Comparison of Methods

Researchers	Do you have remote practice activities?	Do you use any robots as teaching aids?	Do you use Learning Theory?
Pöysäri [20]	Yes	No	No
T. Kaarlela [21]	Yes	Yes	No
B.Tefanuto[22]	Yes	Yes	No
S. Lee et [23]	Yes	Yes	No
This proposal	Yes	Yes	Yes

Therefore, the main objective of this study is to develop a remote method called Hobots to collaborate with the practice of remote teaching in robotics courses, which can be used as a practical tool standard for all participants.

III. Description of the Developed Hobots Method

The proposed method aims to collaborate with practice in a remote teaching environment. Thus, the essence of Hobots is to enable students to collaborate and interact remotely in practical activities. The method, therefore, consists of two key features. The first is modeling the Hobots method's design by scaffolding theory, and the second is the technological components needed to build the virtual remote teaching environment.

The Hobots methodology ensures that the student is always connected to the remote environment. In addition, some techniques reported in the literature [20, 21, 22, 23] have been added. These techniques motivate students, enable collaboration, and help develop skills. The following sections present the design of the Hobots method and its remote teaching environment.

A. *Conception of the Hobots Method*

Fig. 1 lists the instructional guidelines for Vygotsky's scaffolding and the Hobots method. This remote teaching methodology explicitly targets the student's puberty phase. Hobots analyze how each adolescent brings their baggage of knowledge and skills. In Vygotsky's theory, there are zones of development (ZFAs, ZDP, and ZDR). The Hobots method also contains Progression Cubes: The basic Progression Cube (1°CPB) is responsible for identifying the student's baggage of knowledge; the skillful progression Cube (2°CPH) is responsible for the link between the content they are learning and previously acquired knowledge and the self-taught progression cube (3°CAU), where the adolescent can learn autonomously, i.e., by their methods.

Table II shows a standard model of the curriculum structure of the remote Hobots teaching method. Each progression cube contains its structure: content prerequisite, content, and activity. In addition, an example of the contents of the industrial robotic processor subject is given. In short, the progression cubes are the phases and structures that the adolescent will be in.

Scaffolding Theory			Hobots Method	
Development Zone	**Child Stage**		Progression Cube	Adolescence stage
1º ZFA	The student's skill level is low and the teacher must identify the child's level through tasks.		1º CPB	Adolescents come with prior knowledge and the teacher must analyze their abilities by fragmenting tasks with preconditions. At this stage, the student's mistake generates knowledge for the teacher.
2º ZDP	The student's skill level is average and he has already completed some tasks, but he still needs supervision from a teacher.		2º CPH	The teenager has adapted his skills and has already completed some tasks, but he still needs the supervision of a teacher.
3º ZDR	The student's skill level is high and he can already complete the task independently.		3º CPA	Adolescents are self-directed and already complete tasks independently. It's up to the teacher to propose challenges.

Fig. 1: Vygotsky's scaffolding instruction guidelines versus the Hobots method.

TABLE II: Hobots Curriculum Structure

Progression cube	Adolescence stage	Curriculum Structure	Example
1° C.P.B.	Adolescents come with prior knowledge, and the teacher must analyze their abilities by dividing tasks into preconditions. At this stage, the student's mistake generates knowledge for the teacher.	Content prerequisite	Introduction to Industrial Robotics
		Content	Technical Components of a Robot
		Activity	Identifying Robot Components
2° C.P.H.	The teenager has adapted his skills and has already completed some tasks, but he still needs the supervision of a teacher.	Content prerequisite	Linear algebra for robotics programming
		Content	Coordinate systems for robotics.
		Activity	Develop the first joint from 45°, which can move at an angle of 90°.
3° C.A.U.	Adolescents are self-directed and already complete tasks independently. It is up to the teacher to propose challenges.	Content prerequisite	Industrial robot programming.
		Content	Identify the robot's programming methods.
		Activity	Programming industrial robots.

B. *Architecture of Hobots*

The use of technology for education must be well planned. Thus, the architecture model influences maintainability, scalability, stability, and security throughout the lifecycle of the framework [24]. Fig. 2 illustrates the architecture of the Hobots' virtual environment via a component diagram. The framework contains six basic modules (the Integrator Platform, Interface, MQTT Broker, Communication Module, Server, and Robot-X e) to implement the Hobots method.

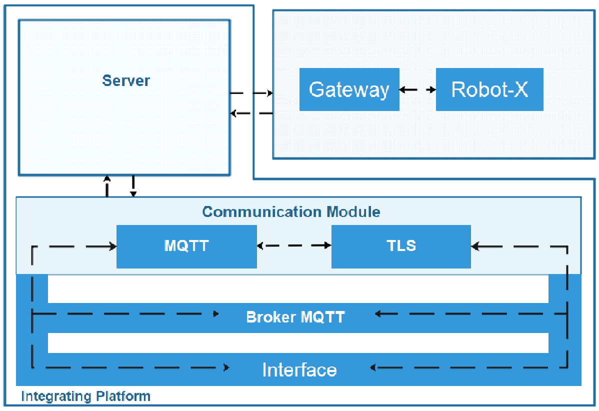

Fig. 2: Hobot virtual environment architecture

The Interface Component is the software responsible for managing remote activities and practices, i.e., the Interface will be used in all the cube's progressions. In addition, the student must understand each step to configure Robot-X.

The Robot-X component contains sensors/actuators and connects to the server via the gateway. The server includes a camera and an interface that remotely manages the X-Robot. The communication component contains two messages queuing telemetry transport (MQTT) message protocols and transport layer security (TLS), which are responsible for transporting the data. Thus, the MQTT protocol has the following essential functions:

Publish/Subscribe - a device can publish a message or be subscribed to a specific topic to receive notifications.

Messages - Messages are the information you want to exchange between your devices. This can be a command or data.

Topics - Topics are how you register interest in incoming messages or specify where you want to post the message.

Broker - The broker is primarily responsible for receiving all messages, filtering them, deciding who is interested, and publishing the message to all subscribed clients. In MQTT, a publisher (device/client) publishes messages on a topic, and a subscriber must subscribe to that topic to view the message.

TLS, which is designed to increase data privacy and security in internet communications, is responsible for secure tunneling. It allows computers in a teacher and student network to communicate securely over the internet [18].

Thus, Hobots architecture is a set of technologies based on the educator Lev Vygotsky's scaffolding theory. In addition, the teacher must follow the guidelines of the Hobots curriculum structure and weaken the content so that the students can expand their understanding more than they would on their own.

After prototyping the architecture, a physical structure of Robot-X with 6 degrees of freedom was modeled (see Fig. 3) to establish practice in remote activity. We built this type of robot precisely because we can fully control the software, communication, and hardware and correct errors during practical activities.

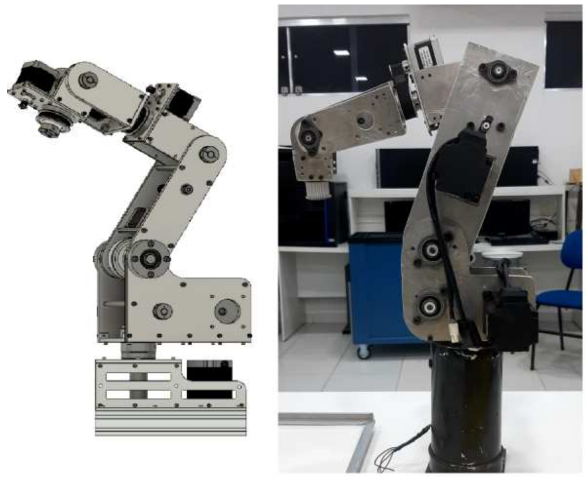

Fig. 3: Robot-X

The X-Robot is open source, has a 1 kg load capacity, and was designed with six axes for the educational environment. Robot-X has the following specifications: arm length, 24.75 inches (62.9 cm); load capacity, 2.2 pounds (0.98 kg); overall accuracy, 1.3 mm; repeatability, 2 mm; robot weight (aluminum), 12.25 kg; shell weight, 5.6 kg; and maximum power consumption, 8.25A (198 W).

C. *Prototype of Hobots*

The prototype Hobots environment interface (Fig. 4) was designed to control the X-Robot angle and degree functions. In this way, Robot-X can be preprogrammed to perform repetitive tasks. The proposed software was called "Human-Robot Version 1.0" (HRV1) and was configured on the server. In short, HRV1 can be used by both the teacher and the student to move, record, and interrupt/calibrate Robot-X.

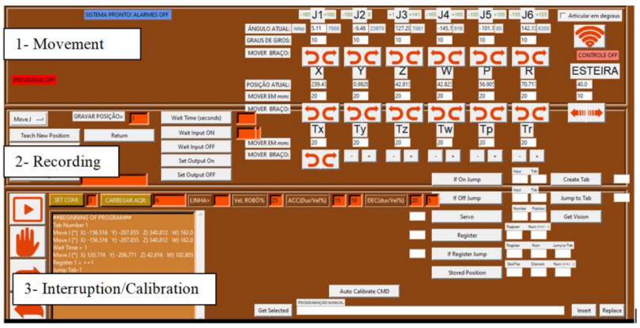

Fig. 4: Interface HRV1

The movement system makes it possible to enter and display the current angles, degrees of rotation, current position, new position, and movements of the robot in millimeters. The recording system is responsible for recording the positions of the X-Robot angles. You can program and save positions, time, speed, return, descent, and ascent acceleration in this area. Next, the interruption/calibration system, which is responsible for emergency stops and calibrating the limits of the prototype's J1, J2, J3, J4, J5, and J6 motor axes, is used.

Fig. 5 highlights the main components responsible for implementing the practice in the remote environment, which has already been discussed in the previous sections.

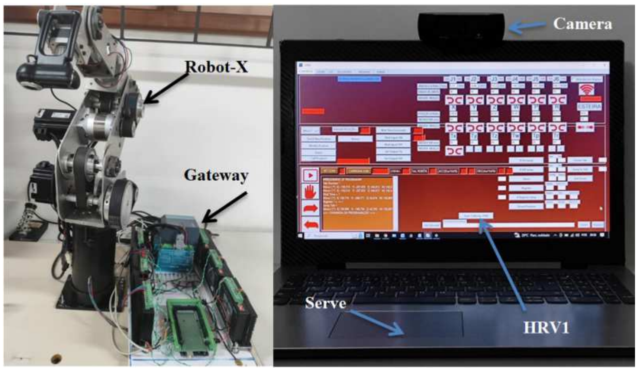

Fig. 5: Components—X-Robot, gateway, server, HRV1 and camera.

In short, Fig. 6 illustrates a virtual remote environment where sharing content and implementing practical activities remotely is possible. In this way, the teacher starts the 1st CPB (Fig. 6) and continually adapts the content according to the student's mental development.

In the 2nd CPH (Fig. 6), the student can conduct the activities in the presence of the teacher but still needs the supervision of a teacher. In the 3rd CPA (Fig. 6), the teacher can present new challenges to the students to find new skills. In this cube, the student is self-taught.

The 1st CPB, 2nd CPH, and 3rd CPA have Hobots steps, which suggests that the teacher applies the methodology below:

Content prerequisites are programmatic contents that are indispensable for understanding the subject. Therefore, the content prerequisite already says there is a subject before the other, which the student must fulfill to move on.

Content is a document that describes in detail the themes, topics, and objectives of the subject or program of study. It serves as a guide for teachers and students, providing an overview of what will be covered during the study period via the Hobots method.

The activity primarily aims to identify and eliminate doubts in the theoretical content. It also gives the students the opportunity to evaluate and validate new concepts learned via the x-robot.

In addition, data are sent remotely via parameters to the x-robot server. These parameters implement the x-robot in the physical environment. Robo-x is a mobile robot system made by the researchers of this proposal for educational, training, and research purposes.

The server is a computer that is responsible for processing and storing remote tasks. It is physically located on university premises and responds to requests from students or teachers.

The camera is a way of checking all the stages of the activities, as it guarantees that the results of the tests sent are reliable. On the basis of this conception of scaffolding theory, a Hobots methodological environment was defined.

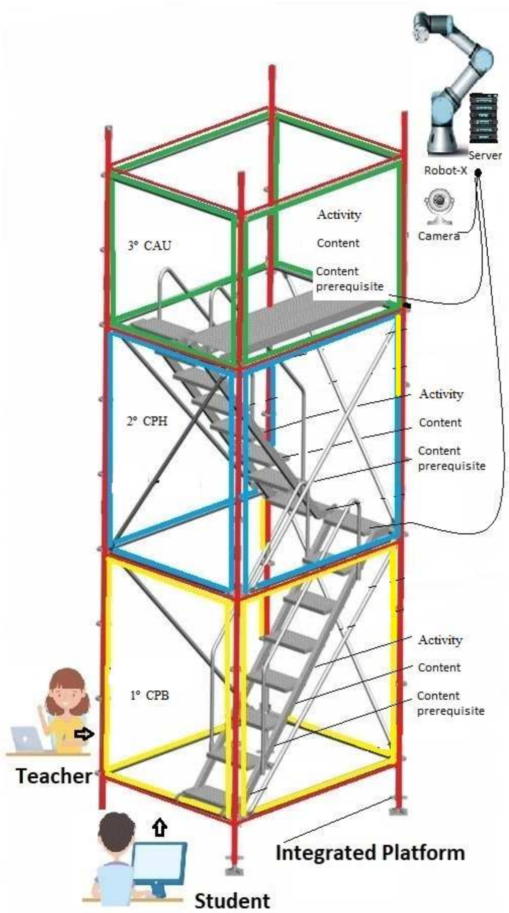

Fig. 6: Design of the Hobots method architecture

IV. EXPERIMENTAL PROCEDURES

The examples in Table II were used to obtain the level of student satisfaction to analyze the Hobots method. A flowchart (Fig. 7) was developed for this case to describe ten (10) activities. In the phase 1 CPB, the teacher is a mentor. In phase 2, C.P.H., the teacher only provides guidance when called upon. In the phase 3 CPA, the student does not ask for the teacher's support; in this phase, the student is self-directed.

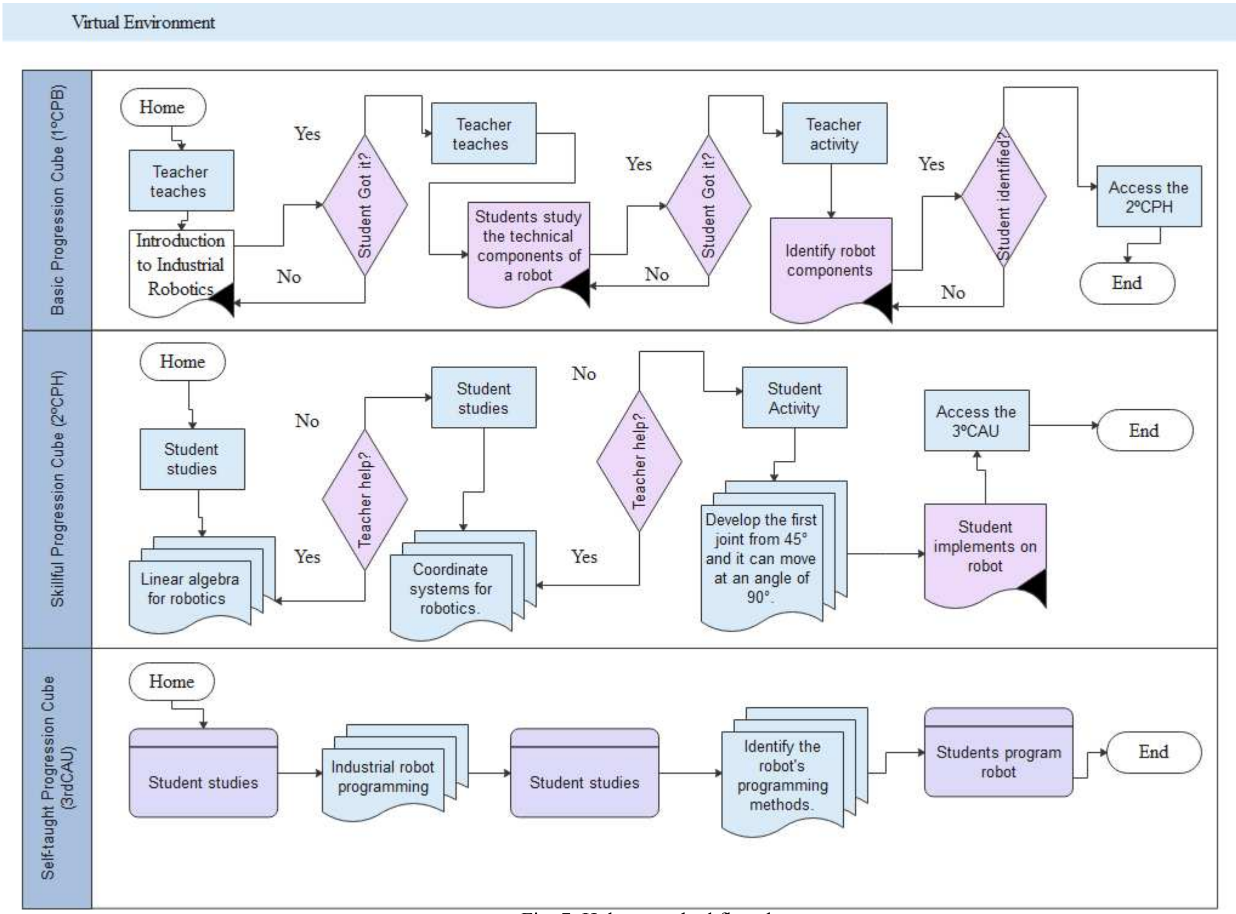

Fig. 7. Hobots method flowchart.

V. RESULTS

A survey was conducted to measure the method's usability via the ISO 9241 Standard - Part 10 - Dialog Systems, which is based on the ten usability heuristics proposed by Nielsen [25, 26]. A scale ranging from motivated, partially motivated, and not motivated was used.

Ten students were asked a set of questions inspired by Nielsen's method. They evaluated the general usability satisfaction of the technique, and the results were promising. In TABLE III, the columns represent the questions according to the legend in TABLE IV.

The TABLE III row shows the ten students' scores for each question. For P1, there were seven motivated students, three partially motivated students, and no unmotivated students. For P2, eight motivated students, two partially motivated students, and no unmotivated students were included. For P3, eight motivated students, one partially motivated, and one unmotivated student were included. For P4, seven motivated students, three partially motivated students, and no unmotivated students were included. For P5, eight motivated students, one partially motivated, and one unmotivated student were included. For P6, seven motivated students, two partially motivated students, and one unmotivated student were included. For P7, eight motivated students, one partially motivated, and one unmotivated student were included. For P8, seven motivated students, three partially motivated students, and no unmotivated students were included. For P9, eight motivated students, one partially motivated, and one unmotivated student were included. For P10, seven motivated students, two partially motivated students, and one unmotivated student were included.

Therefore, taking the weighted average of motivated students, 75% of the students were satisfied with the method according to the calculation below:

$$\sum = (7+8+8+7+8+7+8+7+8+7)/10=7.5$$

For the weighted average of partially motivated students, we had 19% according to the calculation below:

$$\sum = (3+2+1+3+1+2+1+3+1+2)/10=1.9$$

For the weighted average of unmotivated students, we had a value of 6%, according to the calculation below:

$$\sum = (1+1+1+1+1+1)/10=0.6$$

TABLE III. GENERAL USABILITY HEURISTICS

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Motivated students	7	8	8	7	8	7	8	7	8	7
Students Partially Motivated	3	2	1	3	1	2	1	3	1	2
Students Not Motivated	0	0	1	0	1	1	1	0	1	1

TABLE IV. LEGEND OF THE GENERAL USABILITY HEURISTIC

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

From this result, it can be concluded that there is a need to improve the flexibility of the method's handling. Therefore, the first tests reported that the method's usability was motivating, as the method's satisfaction rate was 75%. In the future, more experiments will be conducted to improve the method's efficiency.

VI. CONCLUSIONS

This article proposes a remote teaching method for the teaching-learning process of robotics. In this way, it is helpful to understand each student's progression cubes before starting any activity. The teacher can determine their basic knowledge by giving them a pretest or asking them what they know about a topic before starting the lesson. Many students have distinct levels of knowledge about a subject, so some students will need less help than others during the different structuring phases. However, knowing where each student's progression cube is will allow the teacher to know which students to help.

The progression cube was based on the theories of educator Lev Vygotsky. It highlights the three zones of mental development (ZDP, ZFA, and ZDR) responsible for acquiring knowledge in the learner. In addition, scaffolding theory was explained, which can help students understand educational content through the resources, tools, instructions, and activities used in the learning process.

Next, the architecture of the remote virtual environment is presented. This framework identified the technological components, means of communication, their external properties, and their relationships with their operators.

The method was then developed and evaluated via an activity list. The results show that 75% of the students were satisfied with the technique. Thus, Hobots is an excellent opportunity for students who have a better understanding of the material to help students who have no experience and are still trying to understand it. Collaboration can be beneficial for all students.

Another possibility is to add visual structures such as graphic organizers and images when the Hobots method is used. Graphic organizers help students visualize concepts such as comparing and differentiating, determining cause and effect, or understanding the steps in a process. Students with a greater understanding of a concept can often complete a task without visual aids. Nevertheless, students with a different progression cube can benefit from seeing the added information in a more straightforward format using images or graphic organizers. When students use visual aids, they become more comfortable with the material.

Some lessons involve many new vocabularies, so the vocabulary is introduced to the students before the lesson starts, and they have more opportunities to understand the content. Try to list the words for the students in advance and show them images or short video clips related to the words to activate any prior knowledge they may have about the vocabulary.

The proposed method helps to fragment the teaching material, i.e., instead of assigning all the problems in one day, trying to divide the material into smaller fragments to make it more manageable for the students. Fragmenting the material can help students process information more clearly and focus on one task at a time.

The Hobots method suggests a list of guidelines for its application in the classroom: choose tasks that match the objectives of the curriculum and the needs of the students; allow students to create their own goals on the basis of their current zone of proximal development, which can help increase their motivation to succeed; use a variety of supports to guide students through tasks such as asking questions, creating diagrams and discussing related stories to help them make a connection with the material they are learning and the information they already know; encourage students to use less instructional support, as they become more comfortable with the new content so that they can have less instructional structure and can complete the work independently.

Therefore, the proposed method will achieve its objectives only by following the guidelines in this article. The teacher must use the technique to collaborate with the student's learning and always guide them through the fragmentation of the content. This gradual fragmentation allows students to become independent in their decision-making.

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