HANDZONe: TOWARDS A HYBRID LEARNING SPACE FOR HANDS-ON LEARNING ACTIVITIES

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ABSTRACT

The physical educational infrastructures, which are needed to accommodate hands-on learning activities, can be made more efficient and flexible to answer the increasing interest of the students and respond to the paradigm shifts in education. This paper presents the objectives, methods, and current findings of an ongoing project which is developed with this motivation. The project aims to develop a hybrid learning platform and associated learning methods by using Extended Reality (XR) technologies. The implementation is being developed in a course on robot programming and operation in the Building Technology MSc program of Delft University of Technology. The outcomes of the project will help to improve this course in a blended format towards being more flexible, inclusive, and efficient. Moreover, it will contribute to the field by demonstrating the possible uses of the XR technology to support education with a focus on hands-on learning exercises which require spatial, tangible, and material infrastructures.

KEYWORDS

Architecture Education, Robotics, Virtual Reality, Extended Reality, Human-Robot Interaction, Engineering Learning Workspaces (CDIO Standard 6)

INTRODUCTION

This paper presents the ongoing process and the preliminary results of the project titled: “HADNZONEe: A Hybrid Workspace for Blended Hands-on Learning Activities on Robotic Fabrication”. The project aims to explore the potentials of Extended Reality (XR), Virtual Reality (VR), and Human-Robot Interaction (HRI) technologies in blended education. It started at the Faculty of Architecture and the Built Environment of Delft University of Technology (TU Delft) in September 2022 and has a timeline of 24 months. It is coordinated by Dr. Serdar Aşut, and it is implemented in collaboration between the Chair of Design Informatics, VR Zone, VR Lab, Form Studies Studio, and the Human-Robot Interaction Research Group of TU Delft.

Problem Statement

Blended education requires combining different modes of learning such as synchronous and asynchronous, guided and self-paced, distance and on-campus, or individual and collaborative. Current multimedia-based materials and online platforms are fairly efficient and widely used for audio-visual and verbal communication in education. But they cannot replace a classroom with physical materials and tangible tools such as a model-making workshop or a laboratory. Therefore, the courses which require such facilities are not easily operable in all blended forms.

This project addresses these problems within a course that introduces robot programming and operation through training, experimentation, and production with a robot arm in a laboratory. The challenges towards blending this course include the facts that;

- the available infrastructure and staff hours cannot answer the needs of large student groups,
- each student has a different learning curve, therefore needs a different amount of time to learn,
- the course is not operable when the laboratory is not accessible.

Project Objectives

The project aims to utilize the available infrastructure and staff hours more efficiently, to allow the students to tailor the learning experience based on their skills and expectations, and to enable continuous access to the laboratory. To this end, it aims to develop a digital twin of the laboratory by using XR, VR, and HRI technologies, and to develop an integrated pedagogy and learning materials to be used in a blended learning format.

Proposed Method

The project will output a hybrid environment as a combination of the physical laboratory and its digital twin. It will be accessible through a typical computer, or ideally through a VR headset for a more immersive experience. The students will be able to use it in a game-like setup for self-paced training by following the provided learning materials. It will allow both single and multi-user access to enable both individual and collaborative assignments. It will also allow (controlled) remote connection to the physical robot to enable the users to operate the arm remotely with integrated real-time haptic feedback through a tele-manipulator. Eventually, specific learning activities and materials will be developed to enable the complete integration of the hybrid environment in the course.

Expected Outcomes

The expected outcomes include;

- more efficient use of the infrastructure by implementing certain learning activities with the digital twin,
- more efficient use of staff hours through tailor-made training materials,
- more flexible learning experience which can be customized toward the skills and expectations of each student,
- more inclusive study options which allow students and educators with special needs to participate in education remotely,
- more resilient mode of education which can be sustainable in times of crisis such as a pandemic.

STATE OF THE ART

There are already several good examples that aim to use XR in education and the number of research in this field is rapidly increasing as also presented in a systematic review by Tan et al. (2022) and a critical review by Wang et al. (2018). Also, Cimino et al. (2019) present a review of digital twin applications in manufacturing, which provide insights into their use in educational contexts as well.

Dianatfar et al. (2021) point out the potential of AR, VR, and XR towards increasing the communication between the human and the machine during the design, commission, and operation phases. Ogunseiju et al. (2022) focus on the affordances of mixed reality environments that address the technological gap between the construction industry and construction engineering education. In an earlier study, Sampaio, Ferreira, Rosário, et al. (2010) argue that VR could be applied as a complement to three-dimensional (3D) modeling, leading to better communication whether in vocational training, education, or professional practice. Kaarlela, Padrao, et al. (2022) and Kaarlela, Arnarson, et al. (2022) present an operational example in which industrial robots are controlled remotely through VR for educational purposes.

Olesen et al. (2022) present a comparison of online and hybrid education in digital labs that introduce practical skills to the student and conclude that the hybrid format works well for their efficiency and flexibility. Kharvari & Kaiser (2022) argue that the shortcoming in architectural education such as the lack of sufficient connection between theoretical courses and design studios and students' insufficient reflection on actions can be improved and balanced by using XR technologies. Also, Kamińska et al. (2019) point out the inclusiveness that VR can provide in education, and they emphasize the need for human interaction in learning activities. Schminder et al. (2019) present the development of an educational VR application considering the CDIO standards. Özgen et al. (2021) argue that learning with VR is more enjoyable and effective, and it can strongly enhance problem-solving activities as a complementary tool in basic design education.

Román-Ibáñez et al. (2018) discuss how VR can provide low-cost and efficient solutions for developing lab infrastructures in education. Similarly, Soliman et al. (2021) indicate the benefits of cost reductions by replacing existing expensive laboratories with VR, reduced infrastructure requirement for lab spaces, safer lab working environment for the students, and a market-edge in terms of distance learning VR support and students with special needs.

THE CONTEXT

The HANDZONe project addresses the specific educational activities in the study programs which require the students to practice hands-on design thinking exercises, such as in architecture, building technology, and product design studies. A significant part of education in these programs involves courses in which the students work with physical tools and materials to develop, analyze, and present their ideas. They do so by building different types of physical models and prototypes through which they can explore the spatial and material qualities of a design concept. These tangible models and prototypes are instruments for thinking for a student. They are the interfaces of communication between fellow students and/or educators. They are crucial educational materials and tools which help the student to understand how a design concept can materialize in the physical world. Such courses usually make use of special infrastructures such as a model-making workshop to practice certain craftsmanship. It is very important but challenging to make this type of learning activities blended because the current use of the existing facilities is not flexible enough and they do not allow remote access.

This project aims to develop tools and methods for blended learning activities in courses that introduce the students to Robotic Fabrication technologies for tangible spatial design assignments. The primary focus is the 'Technoledge Design Informatics' (T-DI) course, which is offered in the Building Technology (BT) M.Sc. program of TU Delft. This is a 5 EC hands-on course that is based on active learning and learning-by-doing principles. The students learn how to program, simulate, and operate an industrial robot arm to fabricate spatial objects. They receive instructions on how to use the software and hardware, follow hands-on exercises at the lab, and eventually produce a design prototype by using the robot arm (Figure 1). The robot arm which is used in this course is a ‘Collaborative Robot’ (cobot) as it enables real-time collaboration between multiple users in a safer way. Table 1 presents the main course activity types, their objectives, the type of space they need, and whether the teacher needs to be present or not for that specific activity.

Table 1. Learning Activities of the Course

	Type of Activity	**Objective**	**Space**	**Teacher Presence**
1	Lecture	Understand robot technologies.	Classroom	Yes
2	Lecture	Develop offline robot programs.	Classroom	Yes
3	Tutoring	Operate the robot arm.	Laboratory	Yes
4	Self-study	Operate the robot arm.	Laboratory	No
5	Self-study	Develop a spatial design.	Studio	No
6	Consultation	Develop a spatial design.	Studio	Yes
7	Consultation	Build a spatial prototype.	Laboratory	Yes
8	Self-study	Build a spatial prototype.	Laboratory	No

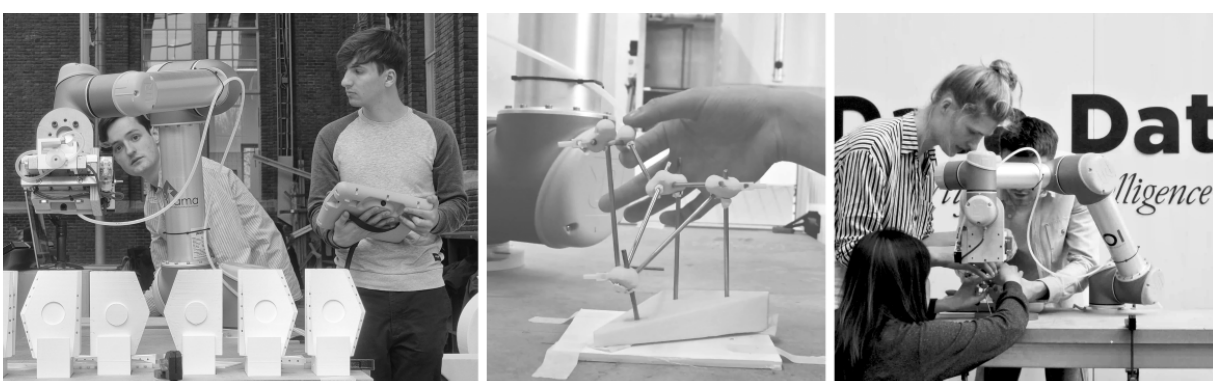

Figure 1. Students, working on the learning exercises with the robot.

This course is a good example of the type of education which this project aims to address. It involves activities that are spatial, material, tangible, and collaborative. It requires the use of specific infrastructure at the faculty. It is a very popular course, and it receives high demand from the students. However, there is always a limit to enrollment because of the limited resources such as lab equipment and staff hours. We are trying to make the resources more flexible and more inclusive to be able to offer the course to more students and to make the learning experience richer. We think that this effort can also make education on robotics more widespread at the faculty level in the long run, therefore can contribute to the digitalization objectives of the faculty. There are already ongoing efforts to make this course blended to use the resources more efficiently. In the first step, online instructional learning materials, in the form of video tutorials, were developed to fit in a blended course format. The more challenging ongoing step is to make the hands-on learning activities (such as robot workspace setups like measuring TCP and frames; and fabrication-related assignments like pick and place, surface contouring, or additive manufacturing.) more blended, which is the purpose of this project.

IMPLEMENTATION

The above-described context points out three major problems:

1. The scarcity of existing teaching resources,
2. The lack of means to customize the learning experience by each student depending on individual skills and preferences,
3. The unavailability of the physical infrastructure during certain conditions such as a lockdown during a pandemic or individual disabilities.

The project proposes to address these problems by transforming the course into a blended form that is practiced on a Hybrid Workspace which enables hands-on learning activities in both synchronous and asynchronous, guided and self-paced, distance and on-campus, and individual and collaborative terms. The Hybrid Workspace can be seen as the integration of the existing robotic fabrication workspace and its digital twin through XR. It will allow the students to access the robot workspace remotely to practice the assignments and gain robot programming and operation skills. The remote access will be achieved through a VR setup, and it will be enhanced with HRI technologies to enable a more immersive and close-to-real experience for learning.

We first created a digital twin of the robot workspace by making a responsive 3D model in Blender software, then importing it into Unity to create the VR environment. This VR environment is identical to the physical setup in the laboratory. It includes a viewport that represents the robot teach pendant interface with the main functionalities of the robot software (Movement Control Buttons, TCP configuration, I/O signals, and the Programming interface with the main commands). The user can use this interface to move the robot, configure TCP, send output signals (only to the tool connector port), and create simple programs. The whole experience is in the VR environment, which enables the user to have a realistic 3-dimensional experience by walking around the robot and viewing it from different angles, unlike a typical 2-dimensional representation on a computer screen. Multiple users can connect to the same VR model simultaneously and use it to communicate and collaborate for practicing the learning exercises. After the VR environment was created, we experimented with three different methods to enable the VR experience and establish the connection with the robot.

Method 1: Integrating VR into the Design-to-Production Workflow

With this method, we aimed to integrate the VR experience into the typical design-to-production workflow which the students learn and implement in the course. This workflow includes the use of Rhino 3D Modelling software, Grasshopper (GH) visual programming interface, and the visose/robots plugin. Typically, the students use Rhino and GH to generate designs. Then, they use the plugin to generate the robot program and simulation. For the VR integration, the plugin was customized to output a JSON object (J) that includes the robot program instructions. Then, J was imported into Unity through RhinoCommon API. A C# block (developed on: https://github.com/visose/Robots/tree/master/samples/Robots.Samples.Unity) was used to initiate the import (Figure 2).

This method works to establish communication between the digital twin in VR and the robot simulation software, and we assume that it would work the same way with the physical robot as well. However, during our experiments, we experienced a latency between the simulation software and the response in VR. Our observation was that the processing of the JSON generator program was considerably slow, which was the possible reason for the latency.

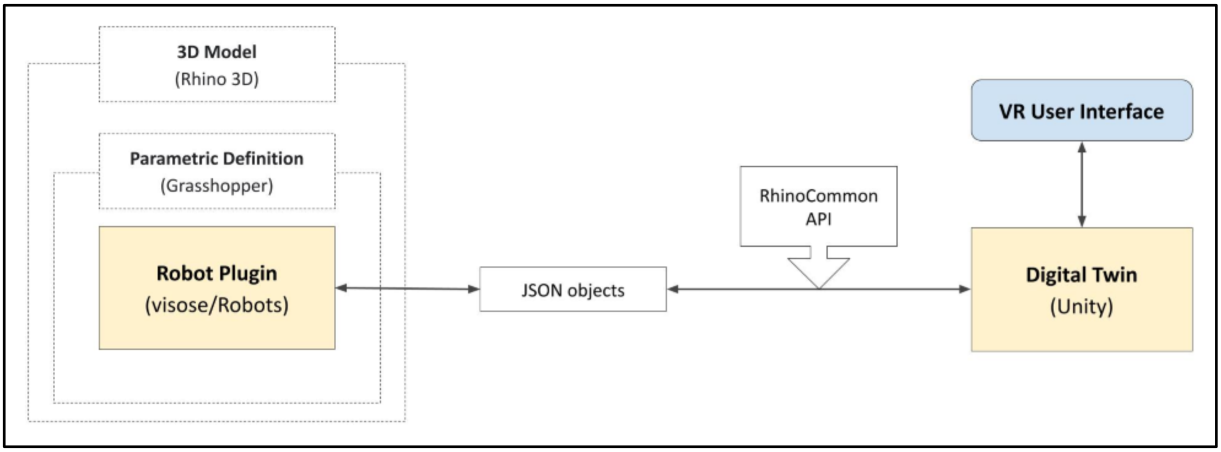

Figure 2. Integrating VR into the Design-to-Production Workflow.

When the integration is established, the users can monitor the robot's operation in the VR environment, as simulated by the plugin. They can also move the robot in VR, by holding and moving either a cube or the robot flange by hand (by using handheld controllers) (Figure 3). In both cases, the robot follows a target (either on the cube or the flange) that updates the program when moved.

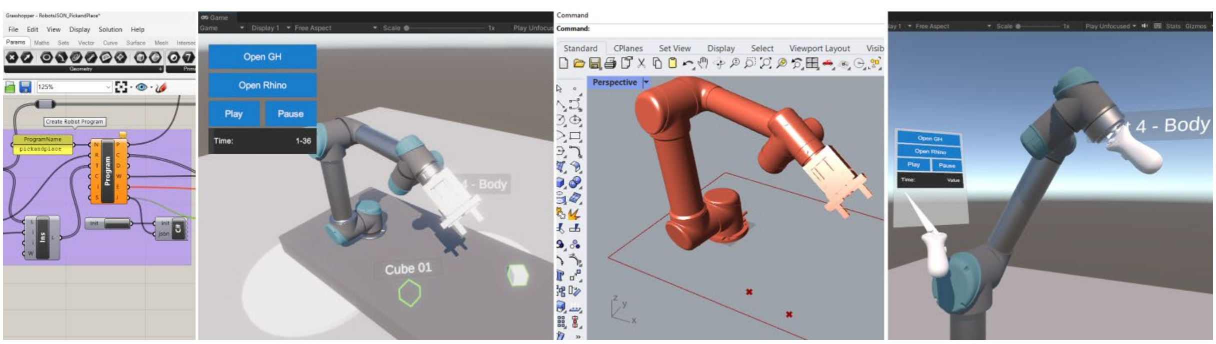

Figure 3. 1st left: GH/Robots plugin and Unity integration. 2nd left: Simulation in Unity. 3rd left: Simulation in Rhino. 4th left: Moving the robot by hand in VR.

Method 2: Connection through MQTT

With this method, we aimed to test a connection alternative through the Message Queuing Telemetry Transport (MQTT) protocol, to evaluate the integration of the physical robot into the workflow, which was developed in Method 1. The connection with the physical robot is not tested yet. We so far experimented only with the robot software platform in a simulation environment.

In this experiment, the Robot User Interface (PolyScope) software runs on an Emulator Software (URSim). An MQTT Connector Plugin (MQTT Connector Professional URCap, trial version) was installed on the software to establish a connection between the robot and the MQTT Broker (Eclipse Mosquitto). A program was written (in URScript) to generate the JSON objects which the connector plugin receives. The MQTT broker enables communication with the Digital Twin (Unity) through a library (M2MQTT for Unity). Finally, the users can monitor and interact with the robot in the VR environment, similar to Method 1 (Figure 3).

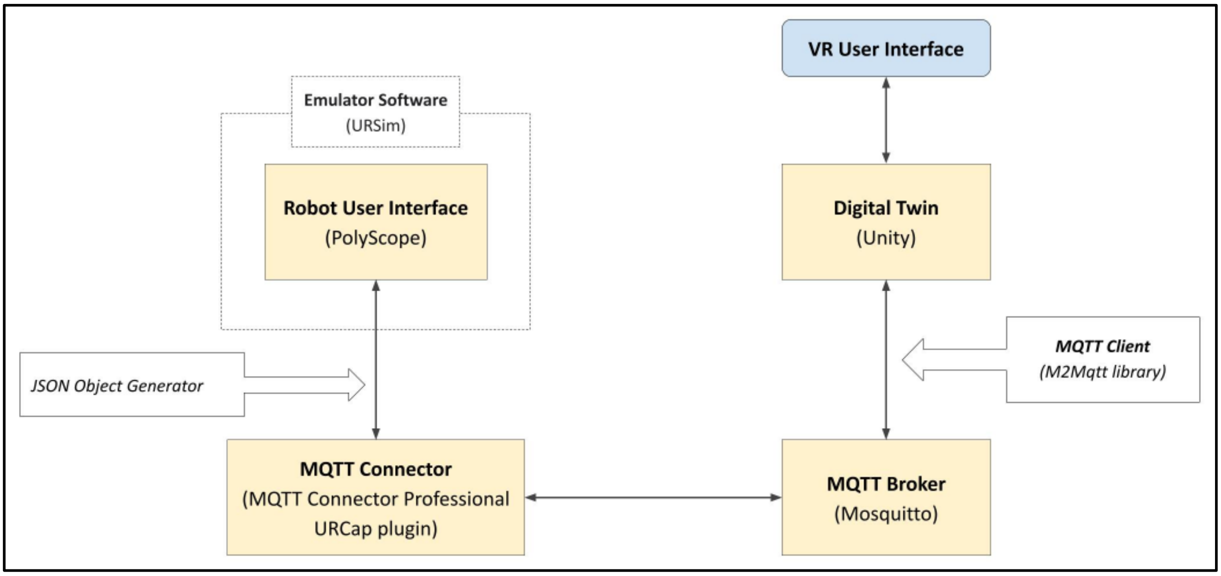

Figure 3. Connection through MQTT.

Method 3: Connection through TCP

With this method, we aimed to test a connection alternative through Transmission Control Protocol (TCP). The connection with the physical robot is not tested yet. We so far experimented only with the robot software platform in a simulation environment.

In this experiment, similar to Method 2, the Robot User Interface (PolyScope) software runs on an Emulator Software (URSim). TCP communication protocol is installed in the robot software by default, and it works through an Internet Protocol (IP) address (TCP/IP). To establish communication through TCP, we created a program that converts the robot software instructions into Bytes. They are received and converted by the Digital Twin (Unity) in the same way, to synchronize it with the robot. Finally, the users can monitor and interact with the robot in the VR environment, like in Method 2 (Figure 4).

This method works to establish communication between the digital twin in VR and the robot simulation software, and we assume that it would work the same way with the physical robot as well. Moreover, no latency was experienced during our experiments with this method.

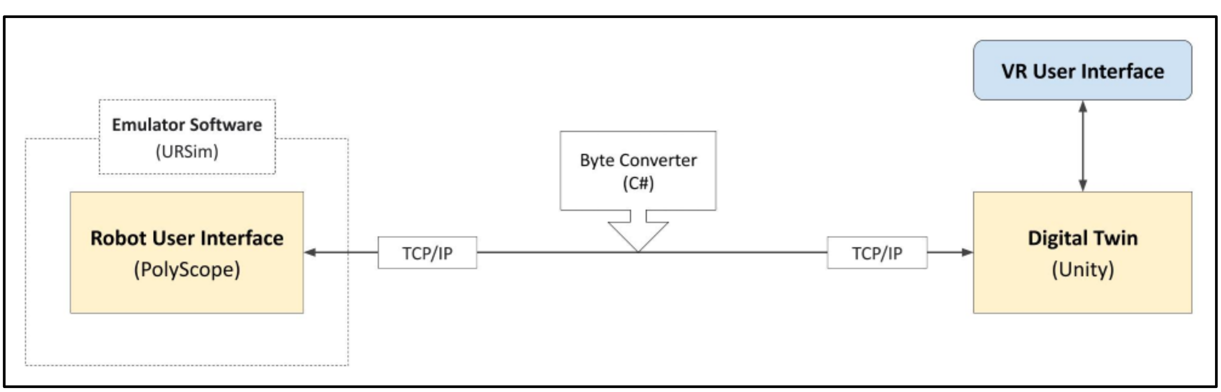

Figure 4. Connection through TCP.

The Use Scenario

The use of the HANDZONe platform addresses primarily learning activities number 3, 4, 7, and 8 as presented in Table 1. With the successful completion of the project, it will be possible to practice these activities in a blended form. These activities include tutoring, self-study, and consultations to gain skills in robot arm operation, then use these skills to build a spatial prototype. In the blended form, these activities take place on the Hybrid Platform, which integrates the physical laboratory and the VR environment. The projected use scenario within the course activities is described here.

The students first follow the video tutorials which demonstrate the fundamentals of robot arm programming and operation within these topics: Robot anatomy and movements, Tool setup, Waypoint and toolpath, Creating a program, Frames, and Design to Production. Each tutorial includes interactive self-assessment and feedback to ensure that they are completed and that the most crucial points are well understood. The tutorials are followed by practical assignments, which will be exercised in the VR platform (Offline Single-user Mode). The assignments are designed in a game-like setup, with scenarios and goals to achieve (such as creating a specific toolpath or moving an object with the robot). They include visual feedback to help the students to achieve the goals and to inform them of their achievements. Thus, fundamental tutoring becomes an asynchronous, distant, individual, and self-paced practice with automated guidance. It eliminates the teachers` workload and the need for physical infrastructure. It enables the students to use as much time as they need concerning their learning curves. And it takes place in a safe and flexible environment.

In the following phase, the students form small teams and meet in the VR platform (Offline Multi-user Mode), including the teachers. Here they practice the next series of exercises which are more complex (such as setting up a custom workspace and building a spatial structure). They collaborate with their teammates to share ideas and experiences, and they receive real-time feedback from the teachers while they work on the assignment. This mode enables a guided, synchronous, and collaborative learning activity while being distant.

The next phase upgrades the offline VR-based learning experience with access to the physical robot arm in the laboratory. In this phase, the students and the teachers meet through the VR platform, which is connected to the physical robot, while a part of the participants are also present in the physical laboratory as well. Thus, the students collaborate on the actual prototype-building assignment while receiving real-time feedback from the teachers. In this scenario, the combination of on-site and distant participants may vary depending on the circumstances. The robot arm can be operated by both on-site and distant participants. Therefore, all of the participants can undertake any role (programmer, operator, reviewer, observer, etc.) in the assignment, independent of how they participate. This mode enables various forms of learning activities to coexist. It allows more efficient use of the resources, namely the physical infrastructure and staff hours. It provides a more inclusive educational setup as it enables students with specific needs (such as disabled or distant students) to participate in the learning activities. It facilitates collaboration between different institutions by enabling them to share their resources remotely.

Challenges

The primary challenge of the project relates to the development of the Online Mode (the real-time connection between the Digital Twin and the physical robot). First, network security needs to be addressed, as the laboratory with the robot is connected to the campus network. During the project development, we plan to establish connections within the campus only. Enabling access from outside of the campus will be consulted with the ICT support team of the university. On the other hand, accessing from outside of the campus may reduce the connection quality, especially for users who have low bandwidth. This problem can partly be addressed by reducing the resolution of the live streams. However, lagging in interaction may be unavoidable. To address this, there will be an added interaction control layer between the remote controller and the actuator to control the transfer sequences of data to eliminate the lags in case of low bandwidth. This will also increase the safety during the operation of the physical robot.

Another possible challenge relates to the need for equipment. For the most ideal use scenario, the users will need to use a VR headset, which may be unavailable for some students. We plan to minimize this problem by developing the platform with OpenVR standards and allowing the use of devices from all vendors in the market. In the worst case, the platform is usable also without a VR headset. In this case, the user will access the platform with a typical computer, which will offer all of the functionalities without the VR 3D experience.

Another important concern is the means of collaboration during the use of Online Multi-user Mode. The communication protocols between the users during the assignments, and the roles and responsibilities of each user need to be well-defined to avoid confusion and enable seamless teamwork. This concern needs to be addressed when designing the learning activities after the platform is operational.

CONCLUSION

The current findings of this ongoing project are promising for the use of XR to implement learning activities for gaining fundamental skills in robot programming and operation. The students can follow the instructional video tutorials and practice them in an XR environment to learn how to create simple robot programs and operate the robot. The XR experience provides a much more immersive and realistic experience than the 2D representations on a typical computer screen. It is suggested that with integrated feedback, these learning activities can be more efficient and semi-automated self-paced exercises. The application that is demonstrated in this research can provide useful inputs toward developing future learning spaces, concerning the CDIO Standard 6. The following phases of the research are needed to assess the functionalities in complex and collaborative tasks.

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BIOGRAPHICAL INFORMATION

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