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Transformation of Robotics Education in the Era of Covid-19: Challenges and Opportunities

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Abstract: The COVID-19 pandemic has significantly impacted many aspects of our social and professional life. To this end, Higher Education institutions reacted rather vastly to this unpreceded situation although many issues have been reported in the international literature since the emergence of the first global lockdown. As we are now transitioning back to the 'normality', universities and businesses consider the so-called 'blended' or 'hybrid' model as a means of facilitating the transition phase. In view of this decision, several studies can be identified wherein blended learning scenarios are proposed and described. The present work constitutes such an effort. Precisely, while adjusting the lens to the didactic of Robotics courses, we propose a blended learning model via which the laboratory activities are performed without the physical presence of the students in the physical context. The aforementioned objective is attained under the aid of the Virtual Reality technology coupled with the Digital Twin model. We hope that the ideas presented in this manuscript will motivate and inspire more researchers, instructional designers, and educators to consider the adoption of such alternative instructional techniques to mitigate the shortcomings that the remote education setting brings and further to improve the overall learning experience.

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Keywords: Robotics, STEM, Higher Education, Blended Learning, Virtual Reality, COVID-19

1. INTRODUCTION

The emergence of the COVID-19 pandemic led companies, associations, and organisations to shift their operations to the online setting without, however, having the infrastructure or the experience to integrate such a change. To this end, the closure of the educational institutions—as part of the restrictive measures that the governments around the globe adopted to curb the virus—triggered a chain of events that strengthened the existing inequalities while also introducing new challenges that educators and students had to overcome (Azorín, 2020).

To deal with this unprecedented situation, emphasis was placed on the potential of technology to support the educational process. Therefore, after a short suspension of the teaching-and-learning practices, educational institutions all over the world adapted their programs to the online context. According to Arolas (2021), the initial goal was not to provide distance education but to offer remote support services to the educational community. Nevertheless, despite the significant progress that has been made in the field of Information and Communication Technology (ICT), before the onset of the pandemic, the existing and even the newly introduced services could not meet the increased demands (Aboagye, 2021). Besides, the large-scale study that Ma et al. (2021) conducted revealed that most teachers had never taught online before the pandemic crisis.

Although every educational level faced unique challenges, Higher Education (HE) institutions constitute a transitional stage which prepares and equips the future workforce with the knowledge and the skills that are needed to ensure continues and sustainable economic development. As much inevitable this situation is, researchers and scholars perceive

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the challenges that the pandemic crisis brought as the inception of a new era which presents a significant historical opportunity for digital education, in general, and for the transformation of the traditional teaching-and-learning practices, in particular. This claim is further justified after considering the efforts that universities make in developing and introducing alternative teaching methods to enhance their digital competence and literacy (Daniel, 2020).

Nonetheless, distance education has its own peculiarities. Therefore, to achieve this transformation, universities need to tackle several challenges such as: (a) the immediate transformation of the course materials, both in the undergraduate and the postgraduate level, (b) the integration of novel, pedagogically informed, technologies capable of supporting learners from different fields and disciplines, and (c) the adjustment of the teaching and learning processes to the principles of the distance learning model (Koutselini, 2020). In view of the above, Albrahim (2020) also highlights the multidimensional role that teachers need to adopt to facilitate the learning process and further help learners to develop transversal skills.

In consideration of the educational transformation, several studies were conducted to explore students' views over the advantages and the disadvantages that distance learning entails (Christopoulos & Sprangers, 2021; Karalis & Raikou, 2020). The key-findings denote that distance education is modern, adequate, and convenient but cannot replace the social interaction with colleagues and teachers. Besides, concerns were also expressed about the methods utilised to substitute the activities that were otherwise performed in the classroom context or the procedures followed for the conduct of the formal examinations.

These findings can be interpreted in a two-fold way. On the one hand, they underline the advantages that distance education has but, on the other, they highlight the disadvantageous position that students—and especially the ones that are affiliated to the STEM (Science, Technology, Engineering, Mathematics) education fields—have been at. Considering these observations, the necessity of designing and developing methods and tools that can be utilised to facilitate distance learning practices emerges. Thence, in the context of this work, we account the distinct elements that Engineering courses have and describe a Blended Learning model that can be utilised to substitute students' lack of presence at the physical laboratories.

2. MOTIVATION AND BACKGROUND

2.1 Impact of COVID-19 on STEM Higher Education

Researchers (Aristovnik et al., 2020; Onyema et al., 2020) agree that HE was by far less impacted by the pandemic than the others. Students were already familiar with self-paced learning whereas, distance education was already provided as a didactic alternative in several institutions. Nevertheless, the study that Tarkar (2020) performed summarises the key challenges that HE institutions faced during the shift to remote teaching which are as follows: (a) difficulty in implementing and maintaining the technical infrastructure required for remote teaching; (b) inadequate support in redefining the teaching strategies; (c) absence of tools or methods to mitigate the digital divide. The last challenge increased further the gap between the possibilities of access to education in both developed and emerging countries.

On the antipode, as a fallout of the pandemic, the shift to distance education presented also significant opportunities. According to Mukhtar et al. (2020), the comfort that the new didactic paradigm offered, enabled educators to reach a wider audience (e-learning) and learners to exploit the potential that modern ICT solutions offer to the fullest extent. To this end, universities also started to explore the potential of Blended Learning practices, where lectures were conducted online, while exercises and laboratories in presence (Singh, 2021). Virtual Reality (VR) applications constitute such a developing paradigm, as the have been linked to increased commitment from students' end while also providing a safer learning environment in which many technical skills can be practiced (Pellas, Dengel & Christopoulos, 2020).

2.2 Digital Transformation of Higher STEM Education

The digital transformation of HE is a critical problem that educational stakeholders from different disciplines and fields have attempted to tackle for many years. In the context of this work, the term 'digital transformation' is associated with the integration of solutions that stem from the Mixed Reality (MR) continuum with particular emphasis on the potential of VR to facilitate the conduct of (remote) laboratory-related activities (c.f., Liagkou et al., 2019).

The evolution of VR, especially within the last decade, has been tremendous. Researchers attribute the added value of this medium on the vividness of the graphical context as well as on the increased opportunities that it offers for interplay (Christopoulos et al., 2018). The software evolution of this technology has been accompanied by the equally rapid rise on the available hardware solutions (e.g., Head Mounted Displays—HMD, haptic devices) which can facilitate the conduct of the so-called 'immersive' experiences.

Nevertheless, as with every developing technology, the retail cost and the difficulty in setting up the equipment hinder its capillary diffusion. At the present, fully immersive experiences can be performed only in laboratories that possess advanced technological equipment (i.e., high-end computers, HMD) whereas, the number of students that can participate, is considerably limited.

However, even under these limitations, the potential of VR is still high, especially in STEM education. The findings of the systematic review that Pellas et al. (2020) performed on the potential of immersive VR in STEM education can be summarised as follows:

- It enables learners to access remote environments, that are otherwise difficult or even impossible to reach, safely and securely.

- It provides fertile ground for the design and development of credible operating scenarios, via which a large set of skills can be practiced and trained, under the aid of the gamification technique.
- It mitigates the shortcomings that govern the traditional laboratory training, as it is usually based on the use of models or scale reproductions that are outdated or even obsolete.
- It lifts the spatiotemporal constraints that the presence of learners entails while engaging in activities that are performed in the physical laboratories.
- It facilitates the development of Communities of Inquiry, via which individuals from diverse locations can collaborate to achieve common goals.
- It allows learners to experiment with the integrated procedures, under the aid of the trial-and-error learning scheme, and further fosters the exploration of unknown alternatives, without increasing the operational cost.

The abovementioned perks that the VR technology offers have been reported as mediating factors responsible for increasing the learning motivation and engagement which, collectively, promote the acquisition of knowledge and the cultivation of practical skills.

2.3 Digital Twin in Engineering Education

The 'Digital Twin' is a novel concept that serves as the real-time digital counterpart of a physical object, process, or system (Grieves, 2017). In simple terms, it is the virtual equivalent or the dynamic digital representation of a physical entity (Tao et al., 2018). One of the main characteristics of the Digital Twin technology is the continues connectivity with the other end. The recent developments on the Internet of Things (IoT) have made it possible to achieve reliable, low latency, response rates with almost no delays. Given that, Jones et al. (2020) define three distinct modes of engagement and collaboration (i.e., bi-directional data connections) between the Digital Twin and its physical representation, which are: (a) physical–physical, (b) virtual–virtual, and (c) virtual–physical.

The immense potential that this approach offers has led to its mainstream adoption in several industry sectors with the most notable applications identified in the fields that specialise on the design of new systems or the development of prototype products (Kenett & Bortman, 2021). Typical applications include, enhancement of the design processes, optimisation of operations, prediction of system failures, and validation of the system properties (Jones et al., 2020).

Beyond the added value that this concept brings in the industry context, researchers have identified several benefits also in education (Liljaniemi & Paavilainen, 2020). For instance, the integration of a Digital Twin model can assist learners to explore how a real-world system or a product works before getting physically engaged with it (Sepasgozar, 2020).

2.4 Blended Learning and Engineering Education

Engineering education is a complex scientific field which relies equally much on the dissemination of knowledge distributed both on theoretical (e.g., lectures) and on practical level (e.g., laboratories) (Ożadowicz, 2020). Achieving such balance, when delivering Engineering courses on campus, is challenging but certainly attainable. However, the COVID-19 outbreak prohibited educators and students from accessing the physical university space (Suryaman & Mubarok, 2020).

As a consequence of the above, multiple case studies related to the conduct of Blended Learning activities were introduced and published, even shortly after the first global lockdown. An indicative example is the remote laboratory model that Mohammed et al. (2020) describe. The proposed system incorporates three fundamental elements: (a) a Remote Access Service, which enabled learners to access the university network system, (b) a Switching Matrix, which allowed students to interact with (control) the equipment located at the physical laboratory, and (c) the Experimental Devices, which provided audio-visual feedback to learners. The initial evaluation that the authors performed returned positive and encouraging results. Nevertheless, the authors urge researchers and instructional designers to explore alternative solutions as a means of contextualising the potential of remote laboratories from different perspectives.

3. PROPOSED SOLUTION

In consideration of the wider efforts that researchers and educational technologists currently make to improve the quality of education, we propose and describe an inclusive and cost-effective approach which can be utilised to facilitate the didactic of Robotics in Blended Learning scenarios.

3.1 Theoretical Framework

The proposed solution is based on a theoretical work that has been originally described by Christopoulos, Pellas & Laakso (2020) which takes into consideration the following dimensions: (a) Technology, (b) Pedagogy, (c) Psychology, and (d) Learning Analytics (LA). According to the authors, the proposed 'immersive analytics' system blends information that emerge from various stakeholders (administrators, educators, learners, digital learning tools) and processes them under the aid of machine learning and educational data mining techniques.

3.2 Design Science Research

The proposed solution also adheres to the principles of the Design Science Research as described by Hevner and Chatterjee (2010). In greater detail, after conducting a preliminary study on the challenges raised by Covid-19 in Robotics education, we discovered that the conventional technological solutions are incapable of meeting the

challenges that the remote education setting had imposed. In view of this outcome, we defined the structural elements of a Blended Learning scenario in which the teaching team is present at the university context whereas, the students, participate in the laboratory sessions remotely. For the integration of this scenario, we opted in for the development of a desktop-based VR solution, as it is cost-effective, yet efficient, especially when compared to the other available alternatives (c.f., Petersen, Petkakis & Makransky, 2022). To further enhance the educational potential of this approach, we introduced the Digital Twin model (i.e., a replica of the physical laboratory). In the next section we provide a detailed description of the design and developmental decisions made whereas, in the near future, we have also planned to conduct the formal evaluation.

3.3 The VR Robotics Education Digital Twin Model

Before elaborating on the details of the proposed system (Fig. 1) the following declarations should be made: (a) the VR simulation model has been designed with the educational sector in mind; as a result, its application in the industry sector may require adjustments and/or additional arrangements; (b) particular emphasis has been placed on the Robotics subfield that concerns the 'automation and control' of robots, therefore, other areas of Robotics education may impose different necessities; and (c) for the conduct of the laboratory activities we assume that the teacher in charge has access to the physical space as it is required for the operation of the robots (synchronous learning scenario). For demonstration purposes we include a YouTube video hyperlink (http://bitly.ws/qvu9) which illustrates how the educational solution operates.

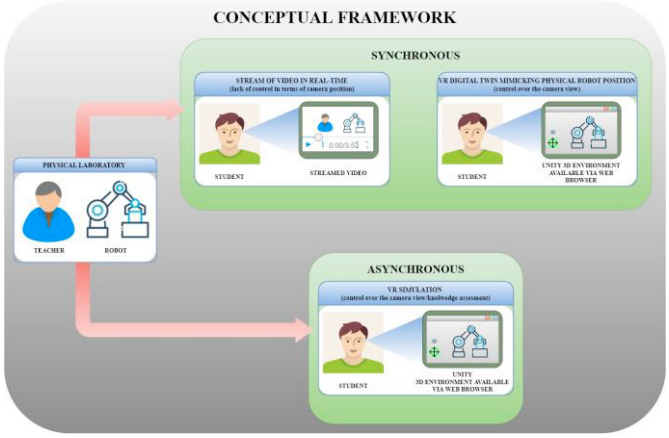

Figure 1. Overview of the proposed conceptual model.

3.4 Design layer

In the first phase, we deconstructed the key instructional characteristics of the course together with the educators in charge. During this stage we defined the main aspects and elements that had to be represented within the 3-Dimensional (3D) VR environment (Fig. 2). In addition, we explored the technical definitions that would guide the operation of the VR Digital Twin. In technical terms, this process concerned the creation of the 3D models (i.e., the laboratory space, the articulated robot), as well as the configuration of the interactivity elements (i.e., the values that would define the movements and the rotation capabilities of the robot). Oftentimes, this step can be the first issue to overcome at the early design phase.

Figure 2. The physical laboratory and its virtual replica.

In the second phase, we sought out to identify the most optimal technology that would facilitate the interconnectivity between the physical and the virtual end. In addition, we explored the available encryption protocols, as a means of securing the networked system. In technical terms, this process concerned the mapping of the data exchange protocol, which can be used for monitoring purposes—such as diagnostics and prognostics, assets' optimisation or verification (in case of an error).

With such a system in place we are also able to acquire usage statistics and other status-related data—directly from the virtual counterpart—without the necessity of being near the physical asset; this is an aspect that should not be underestimated during these times. Beyond the opportunity for data exchange, the integrated approach also allows for the recording and storage of the acquired data which can be utilised for analytic purposes at a later point.

3.5 Development layer

For the design of the VR robotic laboratory, the Unity 3D technology was utilised. The 3D models are designed in scale but with high degree of detail to allow learners to follow the movements from different angles and points of view (free camera navigation). The real-time animation of the 3D models is achieved via data exchanged by means of MQTT, a standard messaging protocol for IoT applications, as it requires minimal resources (bandwidth-wise), offers reliable message delivery, and several security proprieties. The client web application connects to the 'broker' MQTT, to which the laboratory server sends the position data of the robots (Fig. 3).

Figure 3. Real-time simulation complimented with additional information on the process.

Beyond to the synchronous learning mode, we have also introduced an asynchronous learning modality, via which the students can select a variable number of procedures to be executed by the virtual robots. These procedures are loaded into the application by the teaching staff together with a series of questions and corresponding answers, that are shown to the user during execution. Before a question is displayed, the robot movement execution is interrupted so that the student can choose a response from the available multiple-choice answers; only after that the execution can resume until the next question appears or the end of the procedure is reached. Beyond the operational procedures, information and guidance related to the maintenance of the mechanical and electrical components of the systems can also be displayed in the application. Furthermore, in event of an error or failure, the correct procedure to perform the maintenance operation can be indicated, as a step-by-step guide. This second mode can be interpreted both as a learning model and as an evaluation tool with the main objective being the enhancement of the learning experience.

4. DISCUSSION

4.1 Expected Opportunities

The developed platform is deployed as 'Software as a Service' and is fully accessible via a web browser. The networked virtual space offers an accurate representation of the laboratory robots and tools whereas, the Digital Twin system, simulates the activities that take place in the physical laboratory. Although it would be naïve to claim that such an alternative approach can substitute the real experience, we can confidently argue that it can mitigate the shortcomings that are otherwise emerging due to the complete or even partial discontinuance of the laboratory activities. Besides, having such a tool available can facilitate the priming process or assist learners to prepare for examinations.

While considering the multiplatform support that the Unity 3D engine offers, the possibility to deploy this VR application in a Learning Management System, using the SCORM standard protocol, also emerges. Likewise, the user experience can be improved by utilising Head-Mounted Displays or VR googles. As for the backend, the integrated RESTful API underpins the future development, expansion, and evolution of the system while also allowing for the introduction of additional services which can be utilised for the collection and analysis of usage data (e.g., usability, educational value).

Beyond the academic aspect, the proposed VR tool can also be exploited in the Industry 4.0 sector as a means of supporting activities that concern the process control, the maintenance of the equipment or even the monitoring, analysis and prediction of the future behaviour of the involved systems or production lines.

4.2 Identified Challenges

Connectivity can be considered as the main technical challenge that may arise as companies and educational institutions are usually having restrictive network policies that prevent the exchange of data with external networks. Therefore, it is essential to redefine the network rules and policies on both ends to enable the establishment of the communication protocol. From a technical point of view, this type of communication is usually established using web sockets or TCP channels.

Data management may also raise some serious challenges. It is important to process the data from the real counterpart for optimisation and compatibility reasons. These steps can provide bandwidth improvement and are essential for achieving the desired result. Depending on the system selected to implement the virtual representation, it may be necessary to transform and convert the data into a format suitable for the VR environment.

Finally, while preparing the blueprints of the VR scenario, it is important to carefully deconstruct all the configuration elements of the physical infrastructure and subsequently, evaluate the design and development stages together with the educators in charge.

5. CONCLUSION AND FUTURE STUDIES

In this work, we described a solution that can be utilised to support the conduct of Blended Learning scenarios dedicated to Robotics education. The proposed model combines the high representational fidelity that VR applications inherently offer together with the innovative elements that the Digital Twin technology offers.

In the near future, we plan on evaluating the educational potential of the presented solution with both undergraduate and postgraduate Robotics students from different universities across Europe. Additionally, we plan on expanding the content of the VR environment to introduce more laboratory-related activities.

Considering the above, we concurrently recommend educational researchers and designers to consider the design and development of similar solutions, not only in light of the recent pandemic outbreak, but also in view of the potential that these technologies offer in complimenting the learning experience.

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