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Long Paper

Leverage Digital Transformation in Distance Learning for Maximum Students' Engagement by Utilization of the Integrated Technologies of Digital Twin, Extended Realities, and Reinforcement Learning

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Abstract

Purpose – Leveraging online educational services is recently the main concern of academia's top management especially post the COVID-19 pandemic. This created some panic and challenges as to how to achieve the highest possible experiences and engagement for learners in online teaching platforms as well as the challenge of adopting new technologies in an educational context. This paper focuses on these two challenges to achieving the best possible educational digital transformation as the highest possible student engagement through highlighting available innovative educational technologies and proposing a framework based on Unity3d for integrating these technologies in Learning Management System (LMS).

Method – This research focuses on introducing a developmental framework to facilitate the integration of Digital Twin, Virtual/Augmented Reality, and Gamification technologies to utilize the teaching of Programmable Logic Controller (PLC) and Virtual Commissioning.

Results – The implementation of the digital twin prototype concept to replace the physical laboratories could be seen as a good opportunity to reduce costs allocated for purchasing physical laboratories and to increase safety factors of both students and equipment.

Conclusion – Even though developing virtual laboratories based on these technologies is still challenging, the use of the Unity3D platform and other open-source plugins and modules offer a great opportunity to facilitate the development and the integration of these into the LMS.

Recommendations – It is highly recommended to consider integrating these innovative technologies into the LMS to allow students to access PLC laboratories remotely and to make the distance learning approach more applicable and reliable for conducting practical electrical engineering-related tasks.

Practical Implications – Virtual laboratories can be developed using a range of open-source applications and plugins to utilize the integration of the recent innovative technologies, aiming to improve the practical training of vocational and engineering students in PLC programming tasks through having a customizable and scalable application that replaces physical machines.

Keywords – Distance Learning, Digital Twin, Virtual Reality, Augmented Reality, Gamification, PLC, Virtual Commissioning

INTRODUCTION

Just as the new epidemic of Corona "Covid 19" invaded the barriers of time and space, the calls for "distance learning" - which accompanied the spread of the virus - came to sweep the barriers of space and time. A spatial sweep made the absence of fixed spatial barriers a trigger to ascend to different worlds employing the vast internet, and a temporal sweep had the tools to break out of the routine of coming and going and crowding others in search of quick access to a space that might be too narrow for the mind.

With all its audio-visual resources, illustrations, and animations, distance education has shifted from the "memorization" method to an "interactive" method accompanied by visual and audio effects, making the "static" educational process more attractive. UNESCO notes that the wealth of digital educational resources has created new demands on higher education systems and institutions, which include the development of innovative curricula, study programs, alternative learning pathways, and higher education methods, all of which can be facilitated via online, distance education and skills-based short courses.

The organization has developed a set of programs that help with distance learning, including the Black Board application, which relies on designing and marking courses, assignments, and tests electronically. As well as the free social platform Edmodo which provides teachers and students with a safe environment for communication and collaboration, sharing educational content and digital applications. Other platforms such as Google Classroom, which facilitates communication between teachers and students both inside and outside the school, and Seesaw, a digital application that helps students document what they learn in school and share it with teachers, parents, and classmates, Mindspark, an online adaptive learning system, helps students practice and learn mathematics.

However, students view schools and education in general as hard work devoid of fun, while some schools and institutions try to change the concept of education by adding some elements of interaction and fun so that students replace feelings of effort, work, and distress with feelings of play and fun. This is what Gamification systems try to do, by trying to integrate education with games by designing interactive educational curricula that depend on the content and presentation of games, whether in the structure of the curricula itself or through presentation methods.

In addition to gamification, the emergence of many modern technologies has led to an effective contribution to the development of education through the adoption and implementation of Virtual and Augmented reality technologies in the classroom, which help and facilitate the educational process through its capabilities that depend on linking virtuality with reality with the possibility of displaying many of the teaching materials interactively and engagingly to help students gain a deeper understanding of most educational materials through examination, exploration, imagination, and cooperation. The recent talk about the possibilities of Digital Twins and Artificial Intelligence technologies has also led to a continuous search for the best ways to integrate them into education to provide as much of their potential as possible in facilitating the digital transformation and sharing of information, especially through distance learning. The emergence of these technologies has led to the emergence of many applications, platforms, and research that offer and propose solutions to integrate them into education. Through this research, we will present the capabilities of these technologies in the field of distance education, as well as propose a framework to integrate them into the Learning Management System (LMS) to facilitate their implementation and benefits from their capabilities together in the service of educational institutions and students.

Also, one of the major problems facing educational institutions in distance education is the inability to deliver practical educational disciplines and experiments effectively, due to the difficulty of providing practical training distinctly compared to theoretical education (Hampton, 2002), and therefore many educational institutions are moving away from practical training (Mosse & Wright, 2012). This is despite the reliance on video technology to transfer these experiences, as they are devoid of the possibility of learning through "hands-on" experience (Abdel-Salam et al., 2007). Furthermore, especially in technical schools and automation engineering majors in universities and vocational institutes, which require students, for example, to practice machine programming using Programmable Control Logic (PLC) devices, those physical machines are located in laboratories and cannot be used remotely. Relying on traditional PC simulators to solve this problem lacks elements of suspense and excitement, is costly, and its features cannot be expanded easily to match different curriculum requirements. Virtual Commissioning using Digital Twins with extended realities could be considered here as the best solution to overcome the current limitations.

Innovative Digital Services to Enhance Students' Creativity, Teamwork, and Critical Thinking

The Fourth Industrial Revolution (Industry 4.0) is an important part of the process of developing education outcomes. Considering the continuous changes taking place in the local and global communities; Determining the skills required for the learner has become essential. To reach an individual who can deal with the requirements of the later stages of his/her graduation from school; Whether it is related to continuing his/her higher education or engaging in the labor market. Accordingly, the framework for reviewing the performance of schools focuses on developing their educational outcomes, by drawing on the skills of the twenty-first century, which revolve around critical thinking, creativity, cooperation, and communication (Bellanca et al., 2010; Pellegrino & Hilton, 2013). For this reason, educational institutions seek to implement the recommendations of Education 4.0, which is in line with Industry 4.0 standard to transform the future of education using advanced technology, such as Artificial Intelligence, Simulation, Augmented and Virtual reality, and Digital Twins, to train individuals on the requirements and needs of Industry 4.0. Accordingly, the vision of Education 4.0 includes a change in the objectives and content of education to be in line with the skills of the 21st century; In addition to IT competencies and other technical disciplines, Education 4.0 is related to the requirements for creativity, complex problem solving, critical thinking, independence, cooperation, and development of social competencies, such as communication, presentation skills, teamwork ability, and management skill.

Nowadays, it has become possible to achieve these requirements using many modern technologies, which have proven their efficiency in facilitating and developing distance education, due to the effective solutions they provide to develop the student's performance in an atmosphere full of interaction, cooperation, and motivation, especially the application of gamification based on artificial intelligence algorithms. Virtual and Augmented reality applications, as well as Digital Twins with Extended Realities.

Virtual Reality Technologies in Education

Virtual Reality (VR) and Augmented Reality (AR) technologies have emerged to focus on a completely new scene that cannot be touched by the bare hand but is perceptually perceptible through a variety of artificial visual and sound effects, and despite the similarity in the general goal that VR and AR technologies aim for, there are technical differences. Virtual Reality (VR) can be defined as a three-dimensional virtual environment created by computers and visualized through VR-compatible headsets with the use of special applications that support this technology, in addition to special sensors, where the real world is obscured by another virtual world - as if you moved from place to another place - the user is immersed in a virtual environment and interacts with it by simulating many senses such as vision, hearing and touch. Stanković (2016) defined it as, an interactive environment generated by computer programs that enter the child into an artificial world that appears as realistic as a result of the interactions that occur between the virtual environment and the child. Through virtual world applications in which the user becomes a participant with the computer, to produce imaginary events that simulate real events that cannot be previewed in reality, whether because of their gravity such as volcanoes, earthquakes, nuclear and laboratory experiments, or because of their geographical dimensions such as planets, stars, and deep seas, or their historical dimension such as ancient historical events with the aim to bring it closer to the learner or connect a group of learners in virtual classes around the world. This immersion in the learning process is considered an advantage of VR technology because it thus makes the learner an effective participant and interpreter of his perceptions, leading to deeper educational experiences than those available in the traditional learning environment.

Several studies have proven the effectiveness of using virtual and augmented reality technology in developing students' educational abilities and its impact on their twenty-first-century skills. Through the study and review of many types of research related to this topic, Papanastasiou et al. (2019) presented in his research an overview of the various benefits of using VR/AR in refining the twenty-first-century skills, despite the challenges faced by the implementation and integration of these technologies in education, the study concluded that the use of these techniques and tools improves learning and memory, as well as their impact on developing students' creative, social, and educational abilities. Safadel & White (2020) explored the effects of VR in education, their result showed a significant relationship between spatial ability and media use on students' memory recall, and they concluded that VR visualization had a compensating impact on students with low spatial ability. VR technology can also increase engagement factors and help people with learning difficulties with the acquisition of their skills which would increase their independence and wider community access (Florian & Hegarty, 2004). It can also stimulate cooperation and involvement, increase students' engagement, and allows everybody to participate in the education process (Kamińska et al., 2019).

VR applications in education are divided into many uses, which fall under Virtual Laboratory, Virtual Round, Virtual Museum, and other applications covering different educational subjects. Virtual labs are one of the virtual reality applications that have emerged in recent periods. They simulate real labs and obtain results similar to the results of real labs. Their use has spread in many fields, such as science, pharmacy, engineering, education, etc. The need to use this application has arisen to overcome the problems related to the traditional lab, as it helped the learners to learn abstract things and bring them closer to their minds in a sensory image closer to reality, and it also helped to overcome the risks and consequences that the learners may be exposed to while performing the experiments inside the lab (Abdul Rahim et al., 2012).

Many types of research cover different applications of the uses of VR in the development and facilitation of different disciplines in higher education, including its use in the medical field (Figure 1) by facilitating the learning of neuroanatomy (van Deursen et al., 2021), and converting magnetic resonance imaging and computed tomography-based images into 3D models and displaying them through VR headsets (Gaasedelen et al., 2021).

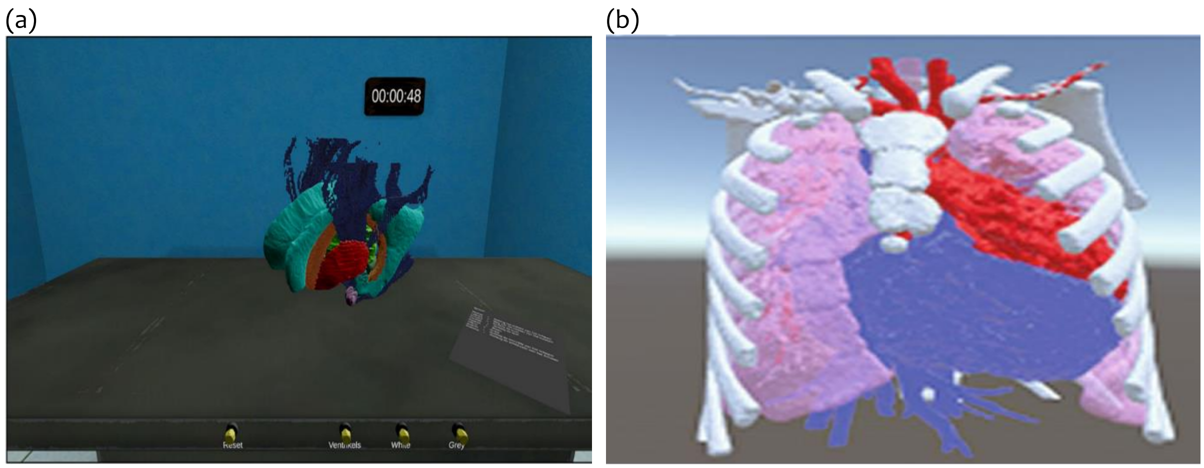


Figure 1. (a) View of the brain model in the VR environment (van Deursen et al., 2021), (b) VR model of the anterior mediastinum of a congenital thoracic model (Gaasedelen et al., 2021)

In the field of electrical engineering, Palmer et al. (2021) presented an idea for designing an electrical laboratory of a DC motor simulator based on Digital Twin and VR. Singh et al. (2021) also presented a VR-based laboratory to train students on how to use electrical laboratory equipment, while Abichandani et al. (2019) designed a VR-based educational system to help students by designing, configuring, and installing solar panels (Photovoltaics), Abdul Rahim et al. (2012) also designed and used VR application in the field of Chemical and Process Engineering Education to introduce students to the work environment without exposure to potential risks. Figure 2 shows excerpts from the previously mentioned research.

On the other hand, virtual tours have become an effective way to use the Internet to visit some archaeological sites, tourism, and museums virtually. Through it, it is possible to make maximum use of it in the field of education and use it within educational environments, as it helps learners in absorbing some lessons that are difficult to refer to or explain with symbols and words, such as previous historical events in history, or a tour in outer space.

Despite the effectiveness and importance of virtual reality in the field of education and training, it is not without drawbacks that may limit its wide implementation as an educational tool. According to previous research, the use of VR technology is limited due to the high initial costs of purchasing the required hardware such as a Head-Mounted

Display (HMD) which is required for generating high-end visual effects, and the high cost of producing virtual programs (Christou, 2010), the lack of flexibility in terms of teacher-student interaction (Kamińska et al., 2019), possible adverse health and safety effects, such as VR sickness, dizziness, and nausea if it used for a long time (LaValle, 2020). However, hardware and software further development may provide a solution to overcome described issues and limitations (Costello, 1997; Kavanagh et al., 2017; Pantelidis, 2010).

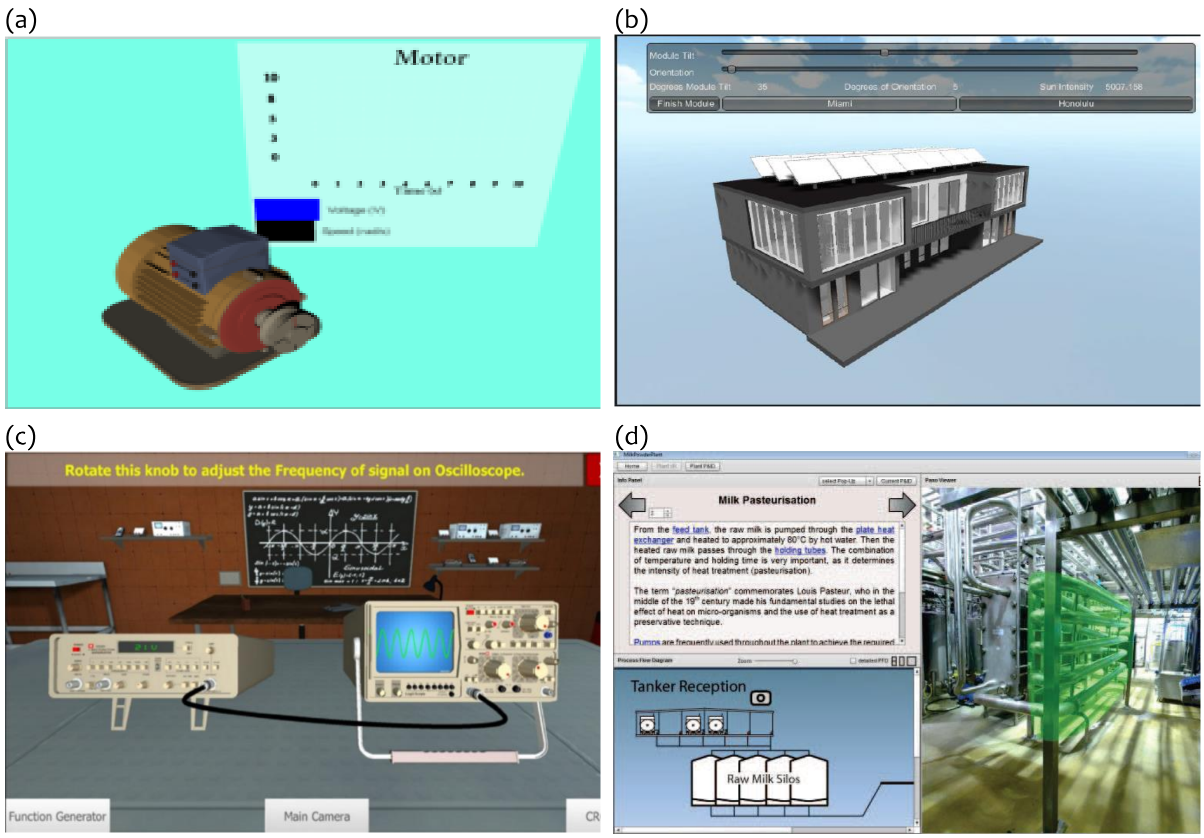


Figure 2. (a) VR DC motor with its data simulation in Digital Twin Player (Palmer et al., 2021), (b) VR interface to adjust installation of Photovoltaics array on a building (Abichandani et al., 2019), (c) VR based oscilloscope and function generator (Singh et al., 2021), (d) Highlighted area of interest of a milk powder production facility displayed in VR (Abdul Rahim et al., 2012)

Augmented Reality Technologies in Education

With the continuous and increasing development in the use of mobile devices in various fields of education, AR is considered one of the innovations in educational technologies that rely on mobile applications, which combine the real environment and the virtual scene to enhance the learner's environment with digital and diverse learning media that allow the learner to interact with multiple and renewable stimuli. This is done by introducing computer-generated virtual data into the user's real world, in the sense of integrating digital information into the user's environment in real-time, to help students obtain, process, and remember information easily, as well as make the learning process itself more engaging and enjoyable. AR technology use is not limited to one age group or a specific level of education, as it can be used equally at all levels of education; From preschool education through college, or even at work.

Fabregat, Baldiris, and Bacca (2014) conducted a systematic review of studies published from 2003 to 2013, the study included an analysis of 32 studies on AR. The results of their study reached a consensus of studies on the effectiveness of AR in improving students' achievement and motivation, as well as improving their ability to discover and to be more creative, however, the study showed also the lack of studies in the aspect related to the variables of designing the learning environment in AR in terms of how to design rapid responses in learning in augmented reality.

Over the last 10 years, many studies showed that using AR in the classroom makes students learn more deeply and more engaged with the material. This technology is currently used in many areas of life, especially in the education sector, as it provides new opportunities and possibilities by creating new learning and experiential spaces that help learners interact with learning content (Billinghurst & Dünser, 2012). Moreover, mobile immersion in the use of mobile augmented reality has aided learning in and out of the classroom to support learning in both formal and informal learning environments by shaping new everyday learning environments (Bacca et al., 2015; Lee, 2012; Sommerauer, 2019). Other research on the effects of AR in education also showed substantial improvement in students' perception and interaction with content (Chen & Wang, 2018; Majid et al., 2015), in understanding and learning process (Petrov & Atanasova, 2020), and in motivation and interest to learn (Velázquez & Méndez, 2018).

One of the main benefits of using AR in education is the ability to replace paper textbooks, physical models, posters, and printed guides with portable and less expensive learning materials with the help of using markers that a mobile phone camera can easily capture and distinguish to direct the learner to the digital learning media which could be saved locally or in the cloud, and as a result, education becomes more accessible. Unlike VR technology, AR does not require any expensive hardware such as VR eyeglasses, and since 62.07% (Bankmycell, 2021) of all teens currently own a mobile phone, AR technologies are immediately available for use by the majority of the target audience. Using AR applications, students can learn even if they are outside the classroom, online or distance education can be delivered easier and more effectively through AR-assisted learning materials. The most popular application of AR in education is its usage directly in the classroom, as it can help teachers to explain topics easily by providing a visual representation of the material, and thus help students to test their knowledge in practice. For example, Herron's (2016) study aimed to design medical education books with AR and measure their effectiveness in understanding medical concepts. The study recommended the inclusion and support of medical library books with AR and showed the effectiveness of AR in medical education and inpatient care training.

There is no doubt that lab experiments and demonstrations are one of the most effective practical options for bringing challenging concepts to life. Due to budget constraints, lack of available equipment, or safety risks, many schools, and universities limit the scope of hands-on experiences for students. This is another fact that is starting to change with the adoption of AR technology and the rapid increase in the number of AR-based experiments and demos (Figure 3). With AR applications like Elements 4D, students can manipulate chemical elements and create interactions between them virtually through their smart devices, rather than just reading about them in a textbook. They can also, through the same technology, perform anatomy of the human body through the Anatomy 4D application, which allows users to explore the human body and isolate the various body systems. Jigs (JigSpace app), EON Reality – Education, zSpace, and other platforms offer also a lot of educational content that is suitable for different age groups and educational levels, which facilitate users with a more comprehensive understanding of many contemporary technologies and different scientific topics through utilizing the power of AR technology in displaying and detailing the different parts of each content.

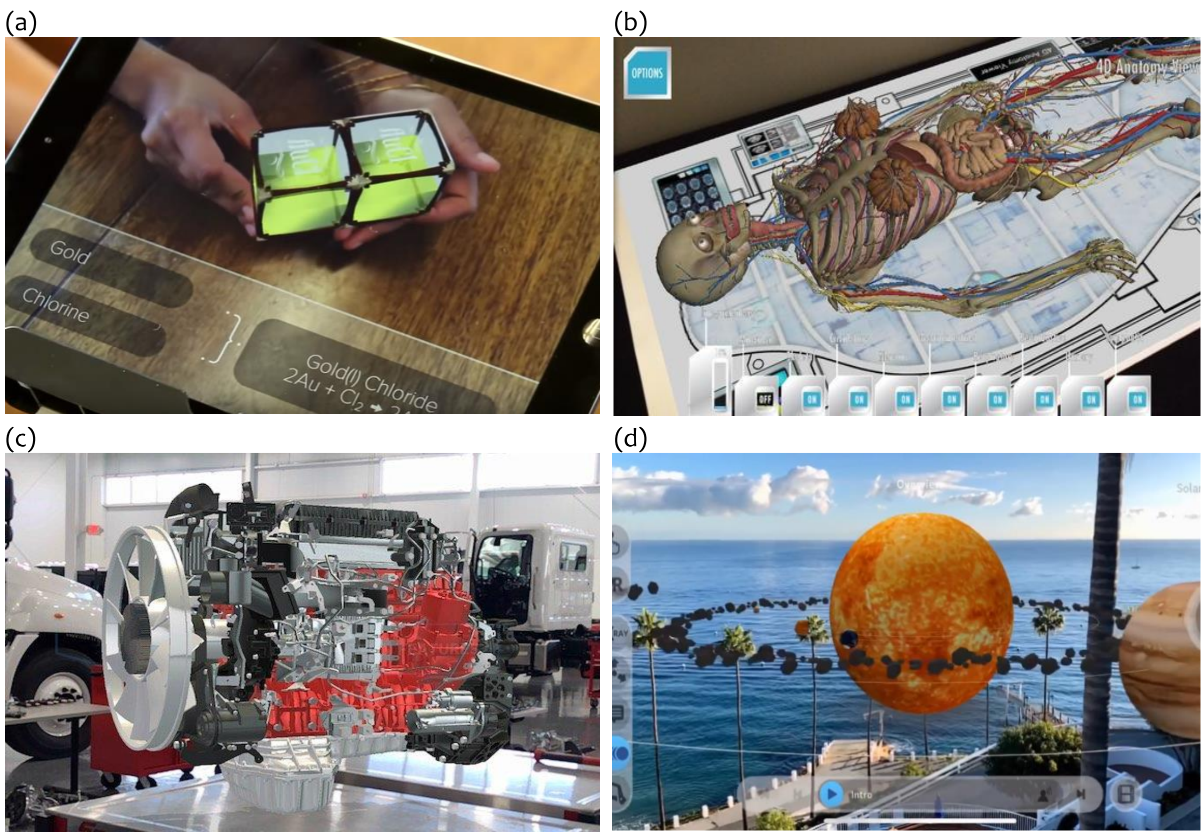


Figure 3. (a) Elements 4D by DAQRI, (b) 4D Anatomy App (c) JigSpace app, (d) EON Reality

The promising capabilities provided by AR technology in education prompted developed countries to pay attention to it and try to take advantage of it in making education more interactive and realistic. In this context, the University of Wisconsin, USA, is using the Augmented Reality Interactive Storytelling Engine (ARIS) program to create a virtual gaming environment that can be used to serve the curriculum. The German company (Metaio) is working on developing interactive books that come alive as soon as the mobile camera is pointed at them. The European Union has adopted a project (iTacitus.org) to teach the history of Europe by focusing the mobile lens on some historical areas to show the visitor the historical events that have passed through them.

Research that relied on the use of AR technology to increase students' enthusiasm and motivation to learn engineering majors as shown in Figure 4. Aliev et al. (2017) used an AR app to display the tools and equipment used in mechanical engineering lessons through scanning textbooks, Guo (2018) and through his research to improve engineering education using AR technology developed an AR-based learning module to help students to learn Manual Material Handling (MMH) in an ergonomics class, his study showed better results regarding the performance of students who used the application compared to the traditional method.

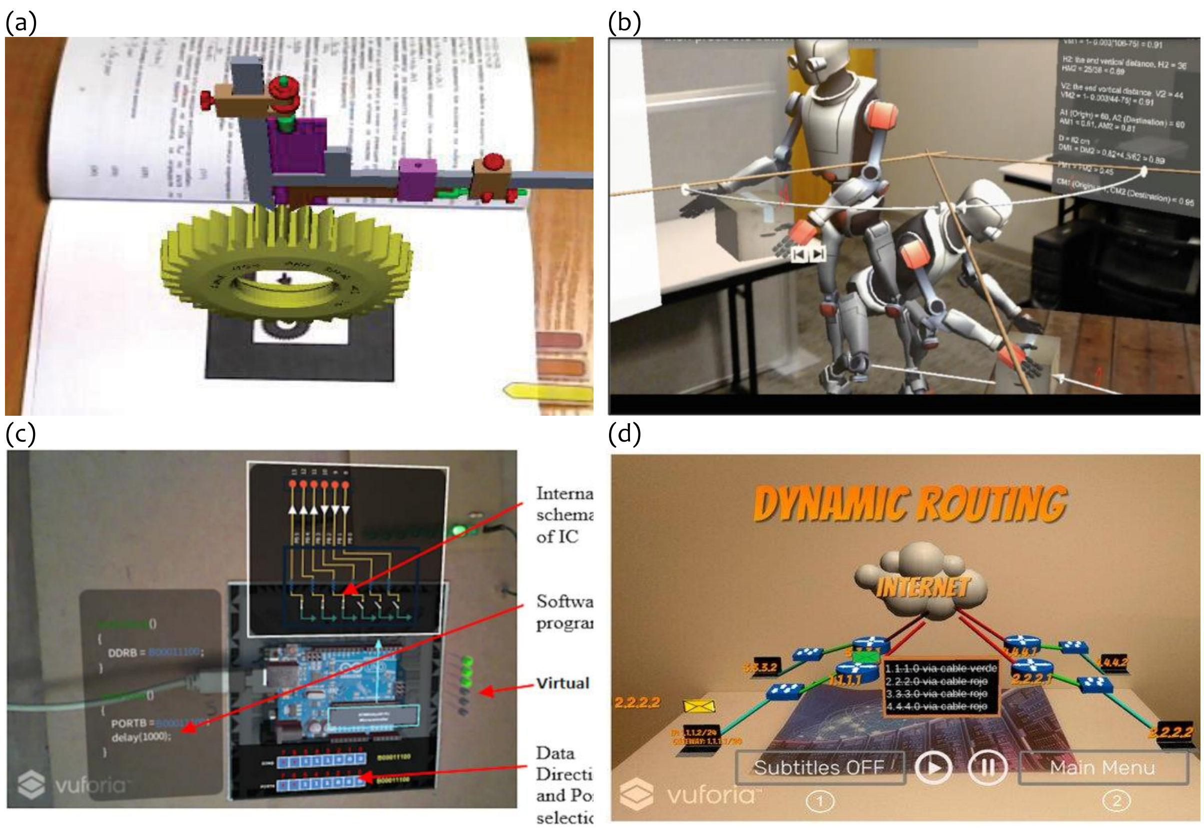


Figure 4. (a) AR guide on how precise gear caliper is used to measure tooth thickness (Aliev et al., 2017), (b) Learning module of AR MMH lecture (Guo, 2018), (c) AR content visualization of internal processing of a microcontroller (Kumar et al., 2021), (d) Routing topology displayed in AR (Criollo-C et al., 2021)

In electrical engineering laboratory training, Martín-Gutiérrez et al. (2015) developed different AR-based applications to guide students while performing practical training in machines installation labs, by showing students individual steps required for connecting electrical wires and components, as a result, the danger of dealing with electrical components, in particular for new or inexperienced students, is limited and assistance time of supervision is reduced. Criollo-C et al. (2021) introduced an effective way to enhance students' understanding of networking topics using an AR-based application. To increase engineering students' theoretical and practical understanding of embedded systems, Kumar et al. (2021) designed an AR-based framework to visualize the internal processing of a microcontroller in a real-time interactive way.

It can be seen from previous studies that research related to the use of AR technology is constantly increasing and the methods used to facilitate the learning process differ based on the educational purpose and topic associated. We find also that the strength of using AR technology is in the possibility of displaying and detailed visualization of complex educational materials enjoyably and interactively compared to traditional methods such as images, videos, and 3D animations, for example, engineering students can display machines, assemble and disassemble its components, and explore its functionality easily and safely, which helps them to develop their visualization process that leads to intellectual development and creativity. Through guided training using AR-based applications, the danger resulting from the direct use of electrical machines and equipment which may occur due to inappropriate usage while conducting training sessions can be effectively eliminated, and the required supervision time and effort can also be reduced significantly.

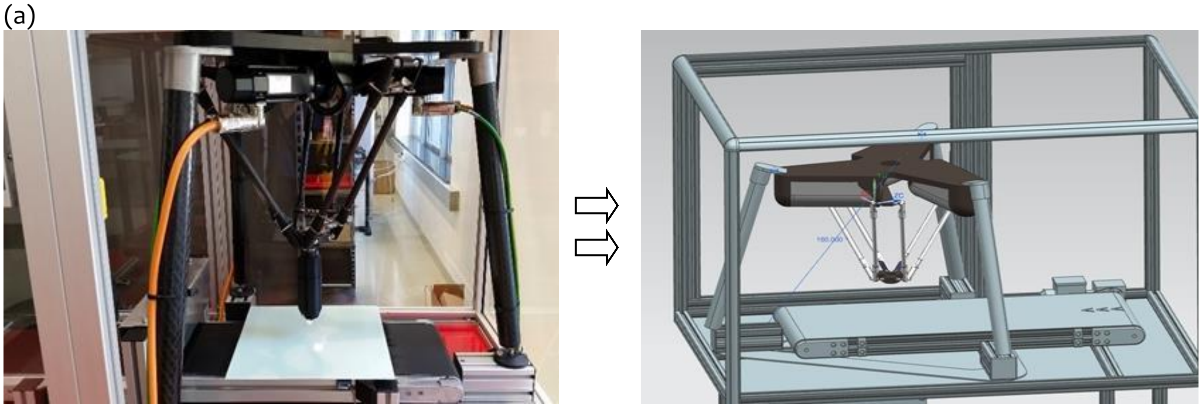
Proposed Framework for integrating the Digital Twin and Augmented Reality in Modern Online Educational

Recently, the interest in Digital Twin (DT) technology has increased among companies and researchers, due to its many benefits in the field of industries and education. Since the technology of DT is still in the development stage, especially concerning its uses, there are many definitions of DT introduced by researchers and industrial companies which are related to its applications and fields. DT can be defined as a digital replica of a physical object such as a real machine or parts of it, and the real object is linked with its virtual digital replica in a way that allows data to be transferred between the two parts, and thus we get a replica that responds to external factors and interacts with them in a manner identical to what the original does. Research has recently tended to find an effective way to use the concept of digital twins in the field of education, especially concerning electrical and mechanical engineering disciplines, and to use it as an alternative to physical laboratories that help students to practice machine programming, for example using Programmable Logic Controller (PLC), or what is known as Virtual Commissioning (VC).

Fernández et al. (2019) study found that using VC to program a robot using DT technology helped to reduce commissioning time, allow greater applicability to different programming scenarios, and helped students to understand processes much easier than the traditional approach. Another study conducted by Liljaniemi & Paavilainen (2020), which revolves around designing a course to investigate the benefits of DT in engineering education, concluded that the correct use of DT increases motivation and learning among engineering students. Zacher's (2021) study also presented some examples of the uses of DT for practical training in scientific laboratories for engineering students at the University of Darmstadt and listed its benefits as ease of preparing experiments, no requirement to install and prepare hardware, and reducing costs compared to setting up real laboratories. Figure 5 illustrates some of such applications.

We find recent examples of the tendency of technical and engineering schools to take advantage of digital twins. For example, the use of digital twins has helped schools in Denmark, to train engineering students to program production lines at the lowest costs, and to expand the number of training stations easily using digital twins (Xcelgo, 2021).

(a)



(b)

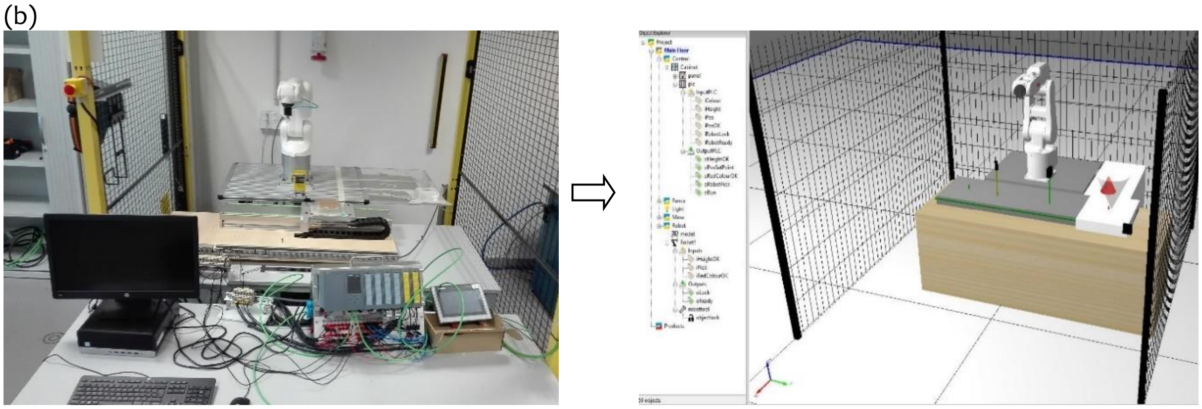


Figure 5. (a) Delta robot in mechatronics lab and its Digital Twin (Liljaniemi & Paavilainen, 2020), (b) KUKA Agilent robot and its Digital Twin (Fernández et al., 2019).

The benefits of digital twins are not limited to electrical and mechanical engineering disciplines, their benefits appear in a study conducted by Sepasgozar (2020), which presented the benefits of digital twins in Architecture, Engineering, and Construction digital pedagogy. Based on the author's conclusion, his use of several modern technologies as an online platform solution, including digital twins along with mixed realities technology, helped students acquire practical and cognitive skills in planning and operating an excavator, sharing feedback as well as improving their social skills and teamwork, on the other hand, it helped trainers to monitor and track students' performance and to provide immediate feedback for students in an interactive way.

It can be seen that there is a great opportunity to exploit the principle of digital twins along with augmented reality technology, gamification, and artificial intelligence to help educational institutions facilitate the training of electronic engineering students in programming machines using PLC. Educational institutions suffer from the inability to provide PLC laboratories, in particular, featured PLC-based machine laboratory for all students at the same time due to several reasons such as high cost, space requirements inside laboratories, needs for a continuous upgrade, downtime due to possible technical issues associated with the wrong programming, and limited capabilities of physical machine laboratory which does not reflect real factories scenarios, and this could be an obstacle to developing education concerned with programming machines using PLC. Furthermore, to manage the impact of Industry 4.0 on industrial engineering (IE) education curriculum requirements, realistic teaching and learning infrastructure such as a Learning Factory is required (Sackey et al., 2017) which has been advised by many researchers (Abele et al., 2015; Enke et al., 2018; Mavrikios et al., 2013; Sackey et al., 2017; Schallock et al., 2018). Learning Factory 4.0 is a factory model according to Industry 4.0 requirements, in which the basics for the commissioning and implementation of industrial automation processes can be learned. In application-oriented processes, mechanical engineering and electrical engineering are digitally linked with professional, intelligent production and control systems. The aim of Learning Factories has been stated as modernizing the learning process and bringing it closer to industrial practices. They are an important way to practice technical knowledge and have been used for educational purposes, training, and research (Elbestawi et al., 2018).

Using the Unity game engine platform (Unity, 2021b), developers can work on programming entire factories and converting them from mere 3D models to virtual machines using Unity capabilities such as physics simulation to transform machine components into interactive components that simulate real machines, and through the available augmented reality engines, the efficiency of the game can be increased by visualizing the DT on students' mobile devices via AR technology. As the proposed framework illustrated in Figure 6, will be mainly based on the virtual replica of a real object without connecting it to its real counterpart, we would use the recently proposed type of DT, namely, the Digital Twain Prototype (DTP) (Grieves & Vickers, 2016). Although the proposed virtual replica can be connected to its real physical machine by the means of a PLC controller, the aim here is to allow users to access the machining laboratory remotely and to reduce the cost associated with purchasing a real machine laboratory that cannot be accomplished by fully implementing DT concept as defined by most researchers. DTP will contain the informational sets such as physical attributes, properties, operating parameters, etc. which are necessary to describe a physical object before producing it (Grieves & Vickers, 2016).

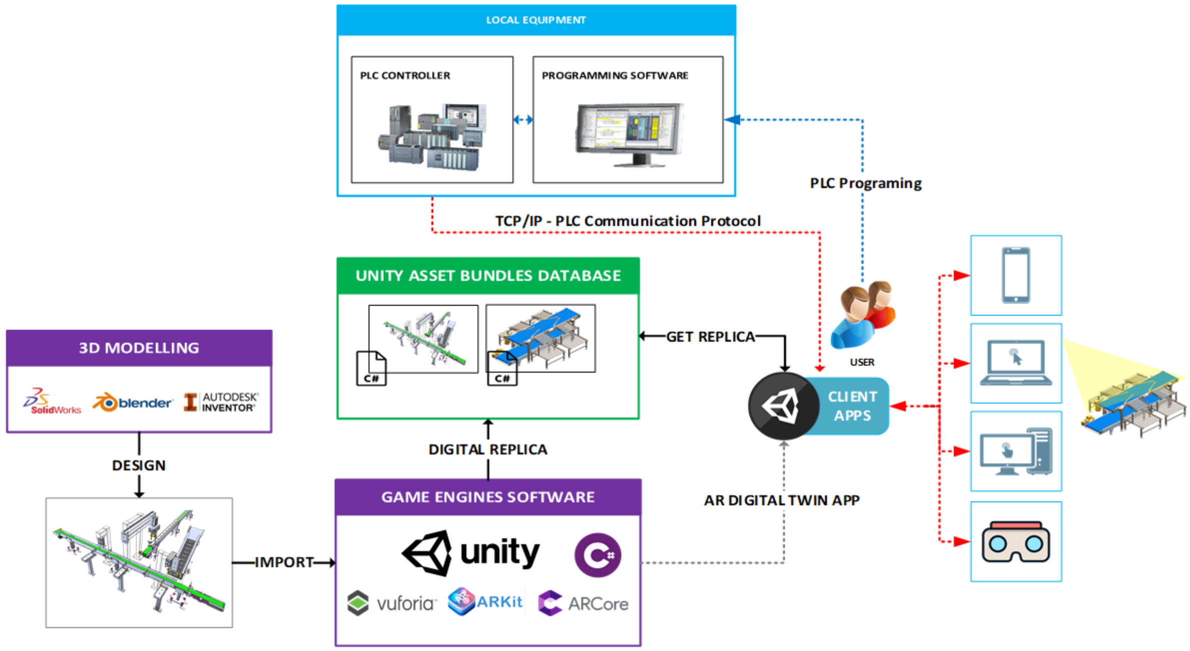


Figure 6. Framework for developing DPTs for utilizing PLC virtual commissioning using 3D Modelling Software, Unity3d, and AR engines. This setup is applicable for users who have access to local equipment.

The control of these DTP occurs by connecting the interactive components of DTP such as virtual sensors and actuators to the PLC controllers using compatible communication protocols either locally or remotely. This solution can also be provided as a remote platform by linking both DTP with the PLC controller through a cloud service such as IBM Watson and Node-Red tool to utilize remote data transactions as illustrated in Figure 7. These proposed solutions will allow students to learn virtual commissioning by having their virtual machines displayed through their mobile phones, eyeglasses, or computer compatible web browsers while using either their own PLC controller and programming software or by accessing PLC controller available in the institution's laboratories, and by providing remote access for students to use the programming software installed in the laboratories, students can download developed PLC program over the physical connection between PLC software and controller while monitoring DT reaction and behavior according to the executed PLC program remotely over cloud service.

AR-based DTP App can be designed to allow users to select and download desirable machines from available machine prototypes, by scanning QR codes or markers which are normally integrated into learning textbooks, 3D models of machines with their associated C# scripts are stored in a database as Unity Asset bundles to keep application size minimum and to allow developers to expand the machine porotypes easily. To increase the efficiency and functionality of the platform, the elements of gamification, automatic assessment, and machine learning algorithm can also be considered and integrated, in particular through Unity's large and smooth capabilities of making use of different associated plugins and modules such as Unity Machine Learning Agents (Unity, 2021a).

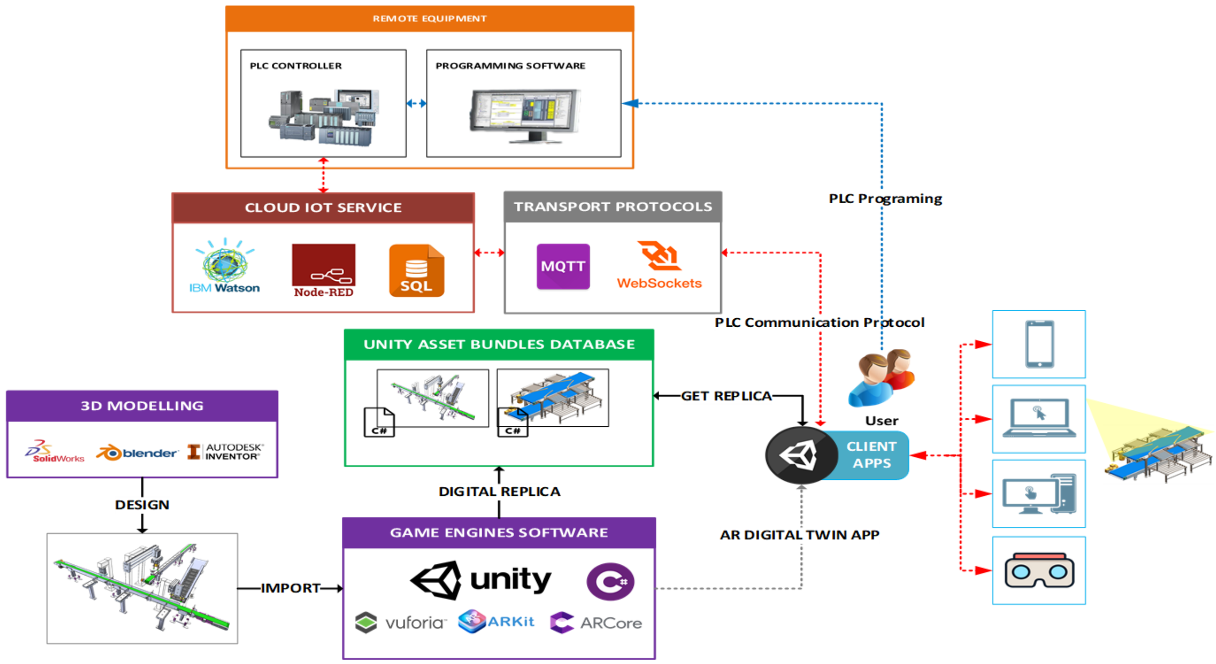


Figure 7. Framework for developing DPTs for utilizing PLC virtual commissioning using 3D Modelling Software, Unity3d, and AR engines. This setup is applicable for users who have access to remote equipment. Remote access to programming software can be provided by any available desktop remote access application.

Proposed Integrated Platform Architecture for Highly Engagement and Collaborative Online Education

Since the use of a Learning Management System (LMS) has become popular due to the tendency of educational institutions to use distance education, it was necessary to integrate the concept of gamification into these platforms using plugins. The LMS is an ideal platform and environment for integrating gamification because it contains algorithms and tools for automatically tracking students' performance, as well as electronic activities and interactive educational lessons through which students can share their ideas and collaborate with others. This is what some educational platforms have already done, for example, Moodle LMS, which is one of the most famous open-source learning management systems, which helped to introduce gamification into Moodle through plugins. Other examples of integrating gamification into LMS are found in many LMS platforms that allow competition between users against learning objectives or Key Performance Indicators (KPIs).

With the increasing reliance of educational institutions on the use of LMS and the huge amount of information related to the performance of learners and educational content, especially after investigating and implementing effective technologies such as gamification, this called for proposing a new name for learning management systems. Gamified LMS (GLMS) is a combination of the traditional features and advantages of the existing LMS systems with the features and gamification systems available. Philson (2014) has proposed a prototype that integrates both LMS and gamification to facilitate the adoption of the principle of learner-centered teaching. Through his study, the author reviewed the current problems facing integrating gamification into education and problems related to misuse that could negatively affect engagement and interest (Philson, 2014 as cited in Deterding et al., 2011). For this reason, the author has reviewed the existing gamification practices and presented a new framework for dealing with these challenges and problems through GLMS which automates and facilitates gamification features in the LMS environment to facilitate the implementation of a learner-centered teaching approach.

The encouragement results of research on the benefits of gamification in education prompted many companies to design education management systems based on the principle of gamification which incorporates points, leaderboards, social learning, levels, badges, earned rewards, and interactive leader boards, such as Adobe Captivate Prime LMS, TalentLMS, Docebo, Academy LMS, ONPOINT DIGITAL, SAP Litmos, Unlock: Learn, Blackboard, Axonify, Growth Engineering's Academy LMS, Accord LMS, LearnUpon LMS, and iSpring Learn. For existing traditional LMS, the gamification concept can be adopted by using specific plugins. For example, for extending the functionality of the open-source Moodle LMS platform, H5P and Badgr tools allow users to create interactive content on different LMS platforms. Other plugins can be used in Moodle which utilize the integration of gamification such as “Level Up!” which allows students to level up in their courses based on experience points earned by completing specific actions in the course, “Game” plugin allow Moodle users to make use of quiz, glossary or questions to create different interactive games, Quizventure plugin is a kind of Arcade-type game which increases users’ engagement to answer predefined multiple choice and matching questions by playing a shooting game. Poondej & Lerdpornkulrat (2019) researched the effect of adding gamification elements to an Information Literacy Skills course created on Moodle. According to the authors and their conclusion, the gamified course developed using gamified features in Moodle and the “Level up!” block plugin engaged very satisfied students. In addition to the available plugins, Moodle platform offers its built-in gamified features and therefore can consider a suitable platform to implement gamified e-learning effectively.

Learning styles of students was a key factor in adapting LMS to learners’ preferences to enhance the teaching and learning process while identifying and adopting player types was mainly considered in many types of research as an essential element for personalizing gamified applications to achieve the best result desired from gamification in education. By using the RL algorithm, Chtouka et al. (2019) proposed a new adaptive GLMS by adopting learner player typology which is based on both users’ characteristics, namely, learning styles and player type at the same time. The authors stated that the proposed approach optimizes the efficiency of the adaptivity of a gamified learning platform as a result of considering and integrating students’ behavior and preferences in the learning and game environment at the same time.

To enhance the selection of learning outcomes for students based on their specific requirements and capabilities inside a specific learning context, Raghuveer et al. (2015) has introduced a Reinforcement Learning System (RILS) based on the RL algorithm which recommends appropriate learning outcomes and suitable course for learners. According to the authors, the proposed RL algorithm focused on addressing the dynamically changing learner requirements and is used effectively in analyzing learners' information, resulting in generating personalized recommendation policies that match learners' needs.

Recently, some independent platforms have appeared that support content designed using Virtual reality and Augmented reality technologies and present it in an LMS environment to take advantage of its capabilities. However, there remains a need for a unified standard to integrate these technologies into traditional LMS platforms, which normally do not directly support state-of-the-art technologies such as VR and AR, and this is because of using different VR/AR authoring tools that require specific content player based on the game engine used. Researchers provided different tools and approaches to deal with this challenge. Barbadillo & Sanchez (2013) introduced a prototype Web3D Authoring Tool which helps users to create AR applications on compatible web browsers without coding skills, the tool can also be integrated into the LMS environment in form of a plugin that can be used for creating and distributing collaborative activities inside LMS web page while the AR visualization occurs through a mobile application (Barbadillo et al., 2014). A different approach based on the embedding of AR content into LMS as a Sharable Content Object Reference Model (SCORM, (The Advanced Distributed Learning (ADL), 2022)) learning object package has been introduced by de Paiva Guimarães et al. (2017), the authors developed and tested a packaging tool to utilize the integration of AR-based content into LMS as a learning object by compressing the AR content into SCORM package that can be easily integrated into LMS environment, the content of AR can be executed in this case using a desktop PC and a webcam as described by the authors.

Using SCORM tools to compress AR-based content allow users to integrate different AR applications into LMS regardless of the authoring tools used to create the content as SCORM standard does not alert the AR-based content and it includes all required data published by the authoring tools, such as game engines, used to build the AR scene. SCORM packages are used by another researcher who introduced a different approach to integrating AR-based content in LMS. Coma-Tatay et al. (2019) proposed a web-based platform to utilize the creation and integration of educational AR-based content into LMS without the encapsulating of the complete AR-based (3D models, videos, etc.) into the SCORM package as proposed by Guimarães et al. (2017), the AR-based content, however, is created using FI-AR platform, which is based on the European open-source software framework FIWARE (FIWARE, 2022), and developed by authors, saved on FIWARE cloud system, and accessed through a web browser using desktop PC or mobile devices. FI-AR editor allows users to create additional educational content, besides the 3D virtual content, such as questions, and exercises, and attach PDF files and videos. FI-AR export AR application as SCORM package which can be uploaded into LMS, SCORM package, in this case, includes different information such as an ID of the exercise, and relevant information required to display designated AR-based and resources within the FIWARE cloud. Finally, Horst et al. (2020) presented an integration solution that allows the user to access and synchronize the AR web-based content through an external AR mobile application, besides web-browser access. According to the authors, the web-payer and VR/AR features can be accessed through web-browsers on mobile devices which is not entirely supported and can lead to performance issues as these are designed to be executed on web-browsers that run on desktop PCs. The AR-based content, designed in Unity software, can be integrated into LMS as a web player to allow users to view Unity application content directly in the web browser, and through scanning embedded QR codes, users will be directed either to download the corresponding App or to open it falls it is already installed. To synchronize and transfer the current status of the web-player content to the mobile application, the author used Firebase Dynamic Links, which includes a session ID, to utilize the re-direction and to transfer the user to the actual current course content which is dynamically saved in Firebase Dynamic Database (FIREBASE, 2022) that is connected to the web-based LMS and contains users' sessions-IDs and their corresponding course content states.

To make the most of all the previously mentioned technologies, developers can work on creating interactive content based on VR/AR technologies using game engine software such as Unity3d, adding questions and exercises within the VR/AR application, in addition to incorporating part of the principle of gamification such as points, duration to complete tasks, levels, etc., and then integrating the final VR/AR application, produced by Unity3d as a web-based content in WebGL format, into LMS environment using SCORM plugin. However, according to Unity documentation (Unity, 2019), "Unity WebGL content is not currently supported on mobile devices. It may still work, especially on high-end devices" and "Unity does not support XR on WebGL" (Unity, n.d.). These current limitations can be possibly overcome by using Unity WebXR Assets (Mozilla, 2020) which allows users to view Unity VR/AR applications directly on their WebXR-enabled browsers. Another possible solution for executing AR experiences on the web can be accomplished by using Zappar Universal AR Asset for Unity (Grace Vassallo, 2020) . Though the current possible solutions still have some limitations and technical challenges in terms of mobile phone browser compatibilities running on different mobile platforms, WebXR support is still under development and is still under unity platform development consideration (Unity Platforms, 2021).

By integrating points elements in VR/AR applications, the results generated by the VR/AR application can be shared with the LMS manager by the means of the SCORM Java-script, to evaluate the users' performance and apply gamifications' elements to their LMS profiles. The gamification concept can be applied to users' profiles as a part of the unity-designed application itself and/or using LMS built-in features and additional gamification plugins. With the help of Unity Machine Learning Agents (ML-Agents) (Unity, 2021a), developers can integrate machine learning algorithms including Reinforcement Learning to enhance and optimize the gamified application to aid in terminating player type, emotion, etc. The proposed framework is illustrated in Figure 8.

By merging the LMS features of creating educational content, LMS built-in gamification features, and additional AI-based gamification plugins, with the visualization power of VR/AR technologies in creating virtual and impressive educational content, the current LMS infrastructure can be effectively expanded to leverage the digital transformation in distance learning for maximum students' engagement.

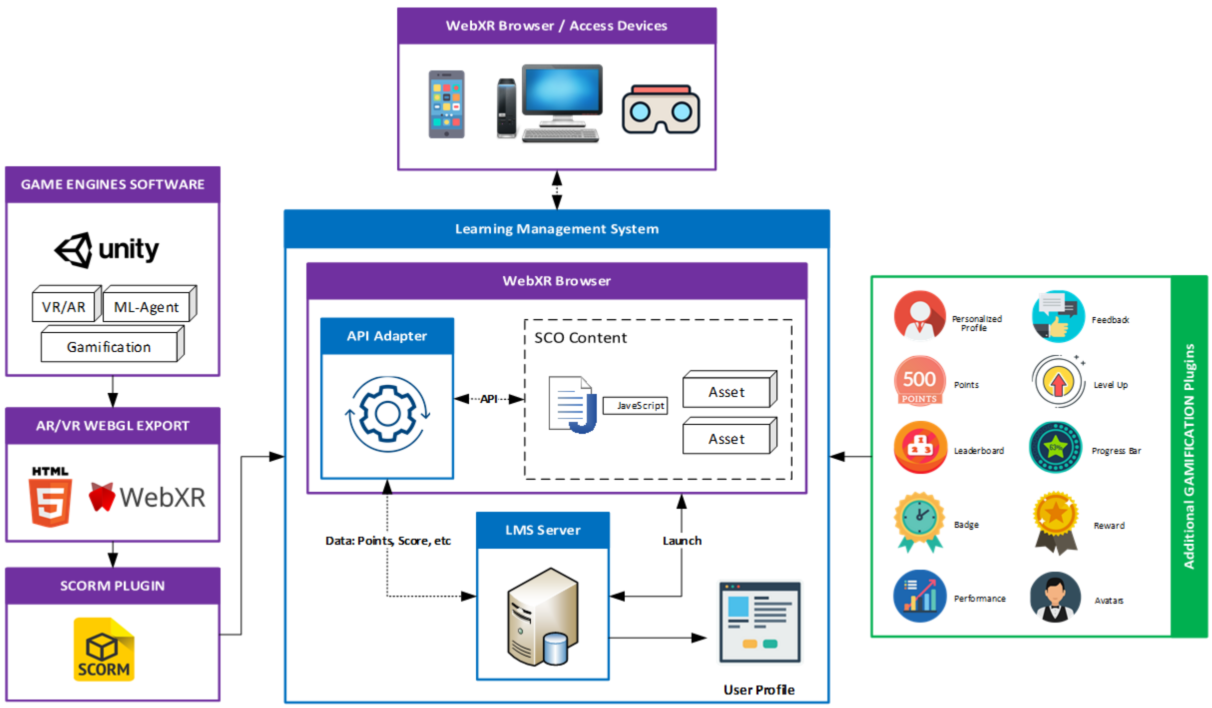


Figure 7. Proposed Framework for integration of Gamified AI-based AR/VR Application into LMS environment using Unity3D and associated plugins.

RESULTS AND DISCUSSION

With the increase in the number of students, universities and schools are facing a problem especially related to the possibility of applying applied learning in machine programming (PLC) in a flexible, easy, and inexpensive way. This is due to several reasons, such as the lack of hardware available in educational laboratories due to the high cost of purchasing hardware for all students, the lack of available space in laboratories, and the lack of sufficient time to train and assess all students. On the other hand, students face the difficulty of not being able to work on such devices from their homes and preparing themselves for practical tests due to the lack of necessary hardware due to the high cost of purchasing such laboratories. Also, researchers face the same concerns in developing their scientific ideas without the need to be constantly present inside laboratories that contain machines and devices necessary to develop their software work related to programming machines.

An AR-based application, containing different interactive 3D virtual laboratories that are capable to communicate with PLC controllers in real-time locally and remotely by using open source S7 communication protocols, would be considered as the first step in replacing the physical laboratories. Different factors will be essential for considering the proposed framework as functional and reliable such as the data exchange speed, application stability, and usability. For this purpose, the system quality will be assessed and validated using the ISO/IEC 25010:2011 software quality standard in terms of functionality suitability, reliability, efficiency, and usability.

A group of technical students and their instructors from the electrical engineering department will evaluate the application usage by conducting relative PLC programming tasks individually. The quality of the system will be measured using a 5-point scale evaluation questionnaire based on ISO/IEC 25010:2011 terms and categories and compared to the case of using real devices (physical machines) as testing beds. Evaluating the application performance and effectiveness in terms of its technical properties will be achieved using smart application benchmarks to measure the device performance, server/API performance, and network performance to assure that the digital twin model, represented as a virtual 3D model, react to the PLC control requests in a real-time manner and exchange digital data smoothly.

CONCLUSIONS AND RECOMMENDATIONS

The emergence of modern technologies has led to a significant increase in the opportunities available to develop student's skills for the twenty-first century. Most studies have agreed that the use of gamification, virtual and augmented reality in education has great benefits in increasing students' performance, encouraging them to innovate and to think critically as well as to cooperate in an educational environment full of excitement and fun. However, the integration of all these technologies into one educational environment is still not straightforward and carries many challenges. Therefore, there is still huge potential for further targeted research to provide appropriate solutions and tools to integrate all of these technologies into LMS easily and effectively, to facilitate the development and sharing process of educational content. Unity3d software offers tremendous capabilities in these areas, with the support of currently available AR game engines which allow creating collaborative sessions, sharing AR-based content in real-time, etc., and with AI plugins, it can greatly contribute to providing smart applications that contribute to supporting the learning process of students.

The proposed Frameworks in Figures 7 and 8 will have several benefits for educational institutions in reducing costs allocated for purchasing automation laboratories, increasing safety factors of both students and equipment, developing related modern curriculums, and improving learning outcomes. On the other hand, students' and researchers' innovation, participation, creativity, critical thinking, and problem-solving ability will dramatically increase by having their portable machining laboratory in form of an AR-based application to practice on DT as a virtual commissioning tool and to test and research new applications and services.

By using the Unity3d supportive extensions as shown in Figure 8, developers can use it to create educational content that combines the powerful features of the Unity3D game engine environment in preparing virtual laboratories and educational courses based on the concept of gamification and extended reality in addition to machine learning algorithms such as Reinforcement Learning, and then integrating it into LMS using SCORM plugin to create content-rich educational materials.

IMPLICATIONS

The proposed application will mainly allow industrial engineering students, researchers, and individuals to work on a digital twin rather than with a physical twin, such will increase learning engagements, improve their practical skills, and enhance the learning environment. On the other hand, the educational and industrial institution will be able to extend the number and the technical capabilities of automation laboratories, and thus increase the efficiency of training while reducing costs and expenses associated with building a learning environment and minimizing challenges and limitations related to developing curriculum for PLC courses.

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DECLARATIONS

Conflict of Interest

All authors declared that they have no conflicts of interest.

Informed Consent

Informed Consent is not applicable: no external data are used as well as no human participants are being questioned or involved in this research.

Ethics Approval

Ethical approval is not applicable: no external data are used as well as no human participants are being questioned or involved in this research.

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