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Extended Reality (XR) in Virtual Laboratories: A Review of Challenges and Future Training Directions

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Abstract. Laboratory laboratories are essential to the education process in all fields of engineering, technology has changed the scientific laboratory landscape. The role of using Extended Reality (XR) technology after the COVID-19 pandemic is unprecedented, the virus had affecting almost all countries concurrently, resulting in an economic crisis, the education sector was the most affected as students could not go to the laboratory to conduct experiments due to the containment of the disease. From this point on, the use of virtual laboratories became a great and effective role for students and the university, as it cost little in the budget compared to the real laboratory. In this paper, the role of virtual laboratories, using extended reality technology, and its impact on education and the future of virtual training in increasing students' efficiency will be discussed in this paper.

1. Introduction

The laboratory has been given a distinctive role in science education and it's a key to understanding the abstract concepts taught in the classroom [1]. Extended reality XR is among the leading technology phenomena in 2020 [2]. This new concept covers many common technologies that guarantee immersive experiences: virtual, augmented and mixed reality. The relationship between real and virtual is becoming increasingly limited and inextricable. Virtual reality completely immerses users in the modern world, detaching them from the real world. AR incorporates with physical world environments and virtual objects computer generated and improves the perception of reality by viewers [3]. Training is continually evolving in order to keep up with changes in society. Technologies are only mechanisms for creating the appropriate learning environment where training can be



performed in the most successful way possible. VR build opportunities for the perception of immersive learning technologies [3]. From travelling to distant locations, making creative 3D objects and interacting with other users in virtual world, the possible near relationships in VR [4].

Laboratory practice is a key instrument for the education of students in engineering. The practical aspect of a research lab-based education provides Learners with a tactile experience that offers students with opportunities to grasp concepts and prepare them for the jobs sector in engineering. One of the problems that many institutions face is that laboratories equipment and machinery are expensive and a feasible alternative solution should be investigated as a result. This includes the introduction of laboratory experiments focused on virtual reality to include a lab-based educational environment that uses a three-dimensional virtual simulation close to that of a real lab. This gives learners an opportunity to virtually conduct experiments and obtain immediate results [5]. VLab are seen as a low-cost alternative that would be Excessively costly for lab experiments (either in terms of cost of instrumentation or supplies) [6], as well as it is suitable at the present time due to the covid-19 pandemic [7]. The concept behind the use of Vlab is to provide students with an authentic lab environment in which experiments can be carried out in a replica of a traditional physical laboratory to solve problems [8]. VLab is now being used to better clarify the tools that could offer solutions [9]. On the other side, it should also be noted that lab classes are high-costly and time-wasting [10].

The preparation of conventional training needs time, effort, and budget, which limits of live training. Laboratory training required qualified instructors [11]. In addition, the regulation of the government and safety organization recommend avoiding some of the fuel material. However, these types of materials could be found in any Lab. The new approaches that employ virtual reality could avoid government regulation and recommendation made by the safety organization [12]. Virtual laboratory's key benefit is the safety it provides when handling dangerous equipment and reagents. As students can conduct experiments at any time, it also offers flexibility [13]. One example of educational technology is the use of VR as a platform for the development of educational content [14]–[18].

2. Extended Reality (XR)

XR is a recently coined term. It encompasses the immersive technologies that “extends” the reality that we experience. It can bring out the imagination from our minds and into the world and give it its own shape and size. The reality–virtuality continuum covers virtual reality on one end and augmented reality with MR falling in the middle. The main purpose of XR is to broaden human experiences, especially the senses of existence and the acquisition of cognition [19]. There is extensive potential for this platform to change how we work, collaborate and generate projects [20][21]. Recently extended reality has become more accessible and economically viable and is now used in daily life especially in the entertainment sector, such as engineering and education[22][23]. The technology is used for a number of uses, like collaboration, training and education [24][25].

A series of recent studies has indicated that extended reality provides the opportunity to co-create experiences like HMDs and Goggles that already have the capacity to produce high-quality graphics and experiences. For example, many research on design teams in a variety of industries have been undertaken to explore ways to enhance the process of producing initial ideas by giving more opportunities to increase the number of iterations. Being able to increase the amount of ideas naturally leads to further exploration avenues and hence a greater chance of creating groundbreaking designs[26]. One of the most common type of XR is VR. and is commonly defined as a computer-generated experience whereby the user is transported into a simulated virtual environment [27].

This will also lead to ideas that are key to making progress and an essential learning opportunity as the design process is proposed [28]. Therefore, VR provides collaborators a vehicle with which to co-create, develop and exchange ideas [29]. This has been used in several studies to assess teaching .the main concepts using innovative methods and how to make the lesson more attractive for students. Moreover, VR tools explored by [28] indicates that VR architecture could have a significant effect on the industry and training Table 1 shows the Mechanisms of XR technologies in Education.

Table 1: Mechanisms of XR technologies in Education.

Mechanisms of XR technologies in Education	Example Work in XR system
Use 3D visualization to teach in a clearer or more visually appealing way	[30], [31]
Connect physical and virtual world to support learners learning by doing	[32]–[34]
Augment physical objects to provide richer digital information	[35]
Role-play or participatory simulation as part of the target knowledge	[36]–[40]
Embedding interactive agent in XR to promote Social-Emotional Learning (SEL)	[41], [42]
Afford learner control and agency through XR controller, sensors	[40], [43], [44]

The intensification of Extended Reality (XR) in training using virtual technology is one possibility[45][46]. Several studies have shown the potential of its utilization, such as 360-degree VR videos [47], 3D virtual worlds [48], and location-based AR games [49], since the conventional need for direct human interaction in creating training in educational environments can be replaced with XR [50]. There are barriers to the use of XR Small and medium enterprises that may lack sufficient capital for the training industry to utilize technology [51]. In addition, learning from history, exogenous shock events have a substantial effect on micro and macro levels while promoting technological innovation [52]. In order to combine both physical and virtual objects, training environments have recently been constructed. The demand for XR in high-risk occupations, such as healthcare, has risen exponentially, due to the need for trained operators and the diminishing prospects for real-world training [6]. In a variety of industries, XR offers educational solutions and allows for more practical, sensory feedback, real-time performance evaluation, and access to training outside the lab [53].

2.1. *Extended Reality (XR) Technologies in Manufacturing*

Over the past decade, digital manufacturing has been seen as a highly promising range of innovations to minimise product development times and costs, as well as to resolve the need for customization, better product quality, and faster demand response [54]. Bridging the digital/cyber/virtual and physical environments in almost all fields of development, i.e. design [55], prototyping [56], learning, marketing, logistics [57], maintenance [58], set-ups, remote guidance, assembly etc. Technologies like XR (i.e. Virtual Reality, Augmented Reality, Mixed Reality). In order to achieve this bridge, it may be beneficial but also to improve the versatility of time-room, i.e. the need not to be at the same position at the same time while operating in a project and to motivate the industry with a quicker and stronger decision-making process [56]. Industry 4.0 can be seen as an industry paradigm shift aimed at integrating all manufacturing agents (machines, robots and operators) in the form of Cyber-Physical Structures through network links and knowledge management [59]. Training method for industrial operators in assembly tasks, using methods such as virtual reality and mining of processes [60]. There are technical obstacles to technology related to its application to industrial reality [61][62]. The majority of these barriers can be solved by early communication with the latest technologies by using

learning factories. This leads to reducing the potential concerns of employees and managers, especially in the context of demographic shifts in industrialised countries [63].

3. Extended Reality in Educational Settings and Student Engagement

Previous reviews generally revealed the trends, advantages, limitations and the vision of educational VR or AR applications [64]–[70]. For example, compared learning outcomes and benefits in VR versus non-VR [71], AR versus non-AR [72], and different VR-based instruction [73]. [74] took a similar instruction-driven approach in its literature review, with a different target (VR in higher-ed settings). Some reviews happen in a particular knowledge domain, for example, investigated how AR technologies support medical professional training [75], science education [76] and language learning [77]. One of the best techniques are Learning by doing. A great number of XR systems seek to facilitate the process of learning by making or learning by doing, by bridging and connecting virtual and physical worlds, e.g. [78]–[81]. Specifically, these systems frequently provide virtual scaffolding, hints and richer information as learners engage in physical tasks. In different fields, such as sports training, VR technologies have been used to create successful virtual learning environments (VLEs) [82], [83], education [84], [85], surgery [86], [87], industry [88].

Virtual technologies can improve students' academic performance and motivation, e.g. [65], [66], [71]–[75], [77], [78], [89]–[91], students' social and collaborative skills [91][92], and students' psychomotor and cognitive skills [94]. Among them VR and AR have long been a popular design space for educational technology, and recently, MR also increasingly applied for educational use [74], [95]. These immersive technologies have the potential to increase learner motivation and engagement [78], promote a full student-centered learning experience [96], support collaborative and situated learning and enable learners to more concretely and tangibly access previously physically inaccessible/invisible content [67]. In effective learning, student engagement and motivation have always played a key role and the selection of the correct engagement and motivation methods can encourage and enhancement of the learning process for students.

Innovative approaches to education are being identified by teachers, using different resources available to promote the learning process and enhance student participation. In classrooms, technology is becoming an important part of productive strategies. Another instrument used by teachers to teach their learners is VR. If technology enhances and becomes incorporated into the educational system, augmented reality will also have a place to increase the participation and encouragement of the students [97].

3.1. *Extended Reality Future of Interactive Education and Training*

The education will benefit from these technologies [96][97]. In the next few years, vocational training will also continue to experience the effect of VR and AR [98][99]. Providing trainees with the ability to experience the reality of being in an unfamiliar working environment is the secret to success in vocational training, but this is also challenging and costly to achieve. In this sense, AR and VR provide a great benefit by allowing students to go back through scenarios again and again without additional cost or difficulty, and to revisit difficult circumstances at their own speed [102]. It is clear that the problem could be easily tackled by using this technology in education.

Some contrasting findings in another previous study on AR in education study. Usability or ease-of-use, for instance, emerged in some studies as the greatest challenge and greatest value in others. The ultimate conclusion of the studies, nevertheless, found that AR-enhanced enjoyment, motivation, and interaction of learners. Through the systematic literature review, they were able to suggest several avenues for future research. For example, a call for more studies specifically focused on addressing usability challenges not just for learners but educators as well. The various fields of research suggest that the benefits of AR and VR over conventional types of media communication such as videos and photographs are increasingly important to consider. However the dynamic nature of how VR/AR is used as a tool often highlights the need for each distinct industry to recognise and adapt the technology [68]. Many other terms have arisen to serve specific aspects of VR or its presentation to a

user to negotiate between the virtual and a physical site. [103] introduced the concept of Reality Skins, where HMD technology would scan the physical room and overlay a texture upon it. In this way, the physical and virtual environments would function in real-time so that the user was able to effectively navigate around the space and obtain some tactile feedback from the physical objects. However, the tactile sensations would not necessarily directly coincide with the virtual simulation of the objects. Multimediated Reality as way technology can extend the mind, body and interaction with the world through its use; these technologies include immersive and augmented types of VR suggested by [104].

4. XR Free and Open Source Software

Computer science has proved to be a field of research that causes students to have mixed feelings. This is especially true for the field of software engineering: while commercial and free and open source software are of significant importance for small to large-scale software projects, this field is particularly attractive [105]. While there has been a lot of discussion about the potential of AR in educational methods for learning, there is a substantial lack of empirical evidence about its efficacy and implementation in higher education. In order to incorporate AR using Microsoft Hololens into UML teaching, the program was defined. Its user interface is designed to solve current software problems. The research is focused on efficacy as a criterion for the success of students and motivational components. Based on two recent literature reviews on the use of AR/VR technology in the general context of education [68][104].

Based on these reviews in recent years, some interesting information was found due to the increasing popularity of XR in teaching science and software engineering. [74]. In addition, few studies have focused on software development, a dynamic collaborative process that involves hands-on expertise from the analysis of specifications through to software. An immersive training platform in virtual reality for software professionals to obtain virtual knowledge based on software development tasks. The participants can acquire important new process knowledge. The results indicate that a complementary VR-based training platform is likely to enhance the experience of inexperienced software developers and ultimately has great potential for software development organisation training activities [107].

Many aspects of the VR software can influence training outcomes, and perhaps the most influential aspect is whether the software includes game attributes [106][107]. VR training programs with game attributes are believed to elicit greater trainee motivation and better align the trainees with the training program. [108]–[110] training program can often sustain trainees' attention during the entire course of the training [111]. Further, gamification elements can prompt beneficial states that have shown promise for training and learning outcomes, such as presence and moderate amounts of challenge [112]. Regarding input hardware, most researchers have differentiated the effects of the keyboard and mouse from specialized input hardware, including motion sensors [113]–[115], and proposed that specialized input hardware produce better outcomes due to their effect on presence and motivation. In their review of immersive virtual reality, [69] found that immersive components can allow individuals to feel objects and events that are not physically present, which may increase learner motivation compared to non-immersive virtual reality.

5. Virtual Reality Head-Mounted Displays (HMD) In Education and Training

Training and educational contexts have only been seen in a few studies, and while some had very promising outcomes, it was not possible to make general statements about the advantages of HMDs in education. All the reviewed studies, with the exception of a single report, concentrated on very short-term use in an experimental setting. Future studies should focus on extended and frequent use and investigate how the results relating to motivation, excitement and time-on-task shift as the learners become familiar with the technology with both mixed methods research. The low average quality and limited number of studies indicate that more and more comprehensive research is required to explore the most promising uses of HMDs in an authentic educational or training context [116]. HMD training applications have advantages in their inherent flexibility, mobility, and accessibility. In a high-fidelity

and immersive virtual environment, training can be applied anywhere and anytime. The idea of studying anywhere at any time provides more versatility for trainees and professionals who are taking courses at training facilities. It can increase opportunities for training program after hours or at the convenience of the trainee, regardless of geographical location.

A wide variety of new possibilities and applications are provided by the utility and flexibility of the development of immersive HMD systems. These personal devices are low cost, versatile, portable and efficient technologies that stand in stark contrast to conventional maritime simulators that are common in the industry. An significant addition to VR, AR, and MR HMDs is that evidence-based investigation can lead to more efficient implementations and the introduction of these emerging technologies, leading to better training and operational performance [117].

5.1. Previous research on Virtual Reality in Safety Training

One environment where Virtual Reality affordances are especially important is safety training. This is the case because Virtual Reality offers trainees the ability to safely act out realistic situations where it is important to make the right decisions and training in reality would otherwise be impractical, risky, or impossible. Thus through Virtual Reality, trainees have the ability to exercise the skills ability to work in a risk-free environment in hazardous situations[118]. There is a rapid growth in the list of fields and studies that have examined the use of virtual reality in safety training. For instance, VR has been used in training of aviation safety (e.g. [117][118], fire safety (e.g. [119][120] pedestrian safety (e.g. [123], traffic safety emergency evacuation of buildings (e.g.[122][123], recognition of risks in work environments (e.g. [126], safety behaviour related to construction sites[127], flooding [128], individual behaviour in tunnel accidents [129], and general safety training [130]. It is important to compare the motivational and educational outcomes in training by using either a text-based safety manual, a desktop VR simulation, or an immersive VR simulation [131]. This training is important and it is best applied in all fields, especially in laboratories.

6. Extended Reality: How to Improve Education Systems

The emerging role of the technologies of virtual and augmented reality in education. Addressing the difficulties of integrating such technology to concentrate on improving the learning results of students is a tool for improving the acquisition of information by learners. In the educational role of technology, participants include students, members of the faculty, organisations, and companies [132]. Within the education sector VR and AR technologies have made their appearance[133]. The challenges to be solved are primarily based on improving the learning outcomes of students. The educational element they have put in motion has been experience as a vehicle to get the student to gain specific knowledge[134]. It is considered the efforts of institutions to provide products and training that will raise the quality of education and training. The ultimate goal for institutions to use this technology is to improve student outcomes throughout the educational process. Increasing the number of students who manage to acquire the minimum knowledge demanded by an expanding competitive market is the only mission of these tools [134][135].

In education, VR has found a new area in which to show its full potential. Education has all the elements that can not only create value to this technology, but also become an extreme differential value[136]. In current educational systems, the learning methodologies with the greatest effect are those that confront students with a specific situation that they have to solve using acquired theoretical knowledge or by improving the abilities of students that are inexistent or underdeveloped until that moment [137]. Students who struggle to reach such educational goals with a low success rate will now be able to achieve the objectives easily. Behind this argument is a justification. These technologies can contribute to make several abstract ideas concrete that should be built within their minds by these students. Because not all students have these kinds of skills and abilities, this activity would be assisted by these technologies, while increasing the success rate. The representation of abstract concepts is another essential field in which virtual reality offers more than significant value [138].

VR also provides a great opportunity in the field of simulation. This technology in virtual laboratories allows easy interaction between students and devices. [139]. Obvious direct advantages include that only a new version of the environment can upgrade the measurement instruments. Without needing to include the physical elements that would obviously reflect a higher investment for the institutions, students would have the chance to work with the newest technologies. Taking this analysis further the cost savings will be immense in space. The underutilised spaces inside the centres would be drastically reduced and would be replaced by "multi-laboratory" spaces in which one or another laboratory or laboratory could be accessed, depending on the subject. These goods are already making themselves available on the market [140]. The risk of inexperience dramatically raising the complexity of carrying out projects with all sorts of consequences could be substantially reduced. student can view a picture of a final product in real space via this technology, without the need to complete a physical manufacturing process. Likewise, health and engineering field sessions would allow the instructor to share information with learners using photographs superimposed on the reality of their classrooms [141]. Through the models, student engagement would be feasible, but the social aspect of sharing real-time experience with real individuals would also be taken into account: their classmates [142].

7. Practical applications, Simulation, Training of Extended Reality

In overcoming the COVID-19 pandemic, the task of using extended reality (XR) technology has been unparalleled in its scale, impacting almost all countries simultaneously and could lead to a new post-pandemic standard at the same time. With the high contagion risk, travel restrictions for inbound and outbound travel have been implemented by governments around the world, major cities have been shut down, and holiday destinations have been off-limits to prevent the spread of the virus [7].

Extended reality has been used in almost every industry to meet ideas like marketing, learning, training, and customer experience. In 2018, the ICRC Innovation Board commissioned a study on VR to inspect the possibility to increase the work of ICRC's VR Unit, the knowledge widened the info on the field of XR developed.

A survey of stress assessment in military missions by using VR environments can be found in [143]. Other work proposes a virtual shooting training system for soldiers and reports that students have more motivation and better scores using it [144]. However, the level of immersion of this system is limited because the authors use a projector instead of a head-mounted display (HMD), which reduces the field of view. A system to train visual scanning tasks is developed in [145], where soldiers have to find people around them and distinguish between civilian and enemies. The results show the importance of a realistic recreation to reduce the gap between simulation and reality and get better results [60]. On the other hand, social system to train veterans with post-traumatic stress to face job interviews is proposed in [146]. This system is evaluated positively by the users, who report a significant rise in self-confidence during the process. The literature contains several references about training systems based on VR. One of the first studies compares VR against conventional systems in the context of laparoscopic surgery [147]. The results show that the students trained with VR are faster and made fewer mistakes than the ones trained with conventional procedures. More recent medical research works confirm these results in the fields of surgery and imagery [144][145]. Additionally, some works propose VR-based tools to analyse human factors in the context of manufacturing, such as ergonomic issues and performance characteristics [146][147]. Furthermore, Virtual reality training to enhance public speaking is a common communication action and has been relevant throughout human history [152]. Despite the prevalence of public speaking, it has been estimated that 75 percent of individuals experience discomfort or anxiety at the thought of talking to a crowd [153]. Virtual Reality Exposure Therapy (VRET) has been shown to be successfully used as a basic treatment for treating public speaking anxiety [150][151]. Similarly, Extended reality has been used to solve refugee issues in Australia, including post-traumatic stress disorder treatment (PTSD) and cultural adaptation to society [156]. Alternatively, AmBus is a bus-sized ambulance that EMS workers use during large-scale emergencies, which introduces a new immersive training application. Evidence suggests that existing

training efforts leave some workers unfamiliar with the AmBus program and unable to respond to an emergency, using new developments in virtual and augmented reality. Ultimately, since workers are better trained, lives can be saved [157].

Interesting technologies as well as new techniques are constantly being applied in the field of the current industrial revolution by providing fertile ground for further research and improvement in the field of industrial engineering. In addition, Cloud Computing has made it possible to provide high-quality services particularly in the controversial field of maintenance. However as modern computers are becoming more complex, maintenance must be carried out by skilled and well-trained workers, while assistance from overseas is timely and expensive. Although AR is a back-bone technology facilitating the development of robust maintenance support tools, they are limited to the provision of predefined scenarios, covering only a limited number of scenarios.

A recent study has been done for the support of remote maintenance and repair (RRDM) operation based on AR, by creating suitable communication channels between the shop-floor technicians and the expert engineers based on machine shop and in a real-life industrial scenario[158]. Moreover, virtual training system used to replace a CNC tool. The system has shown positive transmission of training to mechanical engineering students on the role of tool compensation. Research shows that it is effective in improving basic tool compensation skills [159]. On the other hand, the social and communication dimensions of VR interactions are becoming more important as Virtual Reality (VR) applications are gaining more traction lately. Within the experience, the results were successful in engaging and enjoying the experience through Social Virtual Reality: video conferencing, educational, gaming and movie watching. Such as two participants trying a Social VR Experience. In a virtual environment, they appear to sit next to each other on an office couch, and can interact with each other [160]. Correspondingly, studying the design of virtual reality learning environments in virtual reality aimed at stimulating young people's interest in science through environments in virtual reality. A windmill with three separate learning scenarios includes current demonstrators: simulator, safety training and preventive maintenance training [161].

7.1. Virtual Environment of Things

Extended reality devices have the ability to display this data in full 3D or "virtual windows" in 2D. This gives users greater flexibility to move, resize, and hide this information as needed to help visually manage it. It requires network-enabled sensors to integrate sensor information into XR devices. Network connectivity adds complexity to sensors, but network-connected sensors are more and more prevalent, as evidenced by the rise of the Internet of Things (IoT) for instance, Extended reality in medical practice[162]. AR devices project graphics on top of physical objects and are capable of recovering the camera's 3D path, enabling them to use spatial mapping techniques to map and localise themselves within the environment. These devices can also anchor virtual objects to the physical world, as this interaction provides the user with a new experience as it provides more flexibility and perception of space. The merger of IoT and AR with the use of a new technology called the Virtual Environment of Things (VEoT) [163].

The 4D experience offers spatio-temporal representation in real-time and enables the user to communicate in a highly intuitive way with the IoT network. The demonstration is part of a newly established lab, called the XReality lab, at Texas State University[164]. Extended Reality's different divisions are pioneering new ways of engaging with interactive content, both in the physical and digital worlds. The Internet of Things (IoT) is also taking advantage of sensed data and automation to pioneer new real-world scenarios and use cases. The difference between the physical world and the digital world is bridged by these technologies [158][161].

8. Conclusions

A literature review in this paper was conducted on the use of extended reality techniques and HMD in education and training. XR can offer great advantages for education and training as it provides a direct

sense of things and events far away from us, and it provides a safe environment to avoid the real risks that may occur on the ground.

The extended reality can be carried out by the trainee to do many experiments and repeat them, especially in the virtual laboratories that engineering students can learn, especially in the circumstances of the covid-19 pandemic that the world has gone through. Ultimately I can say it can be as a Google Meet and Zoom application. Since XR provides things that these applications cannot do at the moment.

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