# XRLabs: Extended Reality Interactive Laboratories

Chairi Kiourt[1][a], Dimitris Kalles[2][b], Aris Lalos[3][c], Nikolaos Papastamatiou[4][d], Panayotis Silitziris[3][e], Evgenia Paxinou[2][f], Helena Theodoropoulou[3][g], Vasilis Zafeiropoulos[2][h], Alexandros Papadopoulos[4][i] and George Pavlidis[1][j]

[1]*Institute for Language and Speech Processing, Athena-Research and Innovation Center in Information, Communication and Knowledge Technologies, Greece*

[2]*School of Science and Technology, Hellenic Open University, Greece*

[3]*Industrial Systems Institute, Athena-Research and Innovation Center in Information, Communication and Knowledge Technologies, Greece*

[4]*Omega Technology, Greece*

Keywords: Extended Reality, Virtual Reality, Augmented Reality, Mixed Reality, Gamification, Interactive Technologies, STEM Education, Educational Laboratories.

Abstract: One of the most challenging tasks in Extended Reality based environments is the creation of realistic, interactive and attractive simulation with personalised content, without overlooking the main purpose of the system, which, in our case, is education. This paper introduces the XRLabs platform, which is an Extended Reality platform to assist in the training of students in all educational levels, focusing on the use of simulation for wet laboratories. Within this framework, the proposed systems are based on cutting-edge Virtual, Augmented and Mixed Reality (Extended Reality) technologies. We adopted gamification methods and simulation to enhance the conventional educational practices in laboratories. The highly interactive platform will allow students to enjoy sustainable edutainment experiences, especially in distance/online learning contexts for Science, Technology, Engineering, and Mathematics.



## 1 INTRODUCTION

Science laboratory instruction is a key pillar of science teaching. To achieve effective learning in science courses some fundamental requirements should be met, including basic knowledge and understanding of the experiment tasks and the use of different types of equipment. Information and Communication Technology (ICT) systems are very useful as complementary educational tools, especially in the context of conducting scientific experiments in a wet lab – with the term "wet lab" usually associated with biology and chemistry (Karakasidis, 2013; Bonde et al., 2014; Heradio et al., 2016; Paxinou et al., 018a). Merging virtual reality technologies with interaction has shown to be rather rewarding in laboratory training (Zafeiropoulos et al., 2014).

Several studies reveal the potential benefits of the use of Virtual/Augmented/Mixed Reality in a variety of educational contexts, with such benefits encompassing improvement of users' achievements (Estapa and Nadolny, 2015), learning experience (Bogusevschi. and Muntean., 2019), motivation (Ferrer-Torregrosa et al., 2015), knowledge retention, engagement, and guiding targeted behaviour change to improve the way that various activities are undertaken. The objective is to allow involved learners to begin to take the desired actions in a different context while they experience more fun, enjoyment, and pleasure in their tasks. These technologies are breathing life to the notion that edutainment can be accomplished anywhere, and not just within the confines of a classroom environment. Digital reality is enabling users to bene-

[a] https://orcid.org/0000-0001-8501-8899
[b] https://orcid.org/0000-0003-0364-5966
[c] https://orcid.org/0000-0003-0511-9302
[d] https://orcid.org/0000-0002-9319-1103
[e] https://orcid.org/0000-0003-4102-3260
[f] https://orcid.org/0000-0002-9910-8569
[g] https://orcid.org/0000-0002-5896-0739
[h] https://orcid.org/0000-0003-0120-0488
[i] https://orcid.org/0000-0003-3805-6037
[j] https://orcid.org/0000-0002-9909-1584



Kiourt, C., Kalles, D., Lalos, A., Papastamatiou, N., Silitziris, P., Paxinou, E., Theodoropoulou, H., Zafeiropoulos, V., Papadopoulos, A. and Pavlidis, G.
XRLabs: Extended Reality Interactive Laboratories.
DOI: 10.5220/0009441606010608
In *Proceedings of the 12th International Conference on Computer Supported Education (CSEDU 2020) - Volume 1*, pages 601-608
ISBN: 978-989-758-417-6

fit from immersive experiences and Extended Reality (XR) is undoubtedly poised to change the way users deliver and acquire new information, knowledge, and skills, in several playful learning environments (Pena, 2016).

Playful learning environments focusing on educational purposes is a significant and active research domain (Brown and Vaughan, 2010; Nicholson, 2011). This has taken either the form of Game-Based Learning (GBL) or Serious Gaming (SG). Gamification (Seaborn and Fels, 2015) is the result of applying game mechanics into diverse domains, in order to engage users and enhance their knowledge and performance. The importance of the playing activity has been emphasized in many studies from various domains. Gamification is essentially the use of specific game design approaches and techniques in various environments, in order to attract people in problem solving and to enhance their contribution (Nicholson, 2011). As an important tool in educational processes, gamification has been exploited widely in VR systems(Becerra. et al., 2017; Shin. et al., 2019), with many future promising results for XR applications.

Extended Reality Interactive Laboratories (ERIL) are playful, user-friendly, pleasant, safe, convenient, economic and flexible educational tools, which can challenge, engage and prepare students for their real scientific experiment (Lalos et al., 2020). While physical lab activities offer unique elements in lab learning, nowadays, educational institutions also design learning activities with Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality simulations (de Vries and May, 2019). VR differs fundamentally from AR; in VR the learners experience a computer-generated virtual environment whereas, in AR, the actual environment is enhanced by computer-generated information.

The main motivation for our work draws on the investigation and the development of an educational system for Science, Technology, Engineering, and Mathematics (STEM) education, for all levels of education. We focus on the development of an integrated system that is not affected by geographical, financial and time constraints (Reigeluth, 1999), as would be the case with conventional educational procedures, which require laboratory equipment.

The main contribution of this paper is the presentation of the idea and the development of a dynamical educational XR platform for wet laboratory instruction. With regard to this framework, the proposed platform aims to enhance the educational practice through a powerful integrated system, encouraging certain activities through dynamically synthesized and gamified interactive elements, not as a single encapsulated event, but through a series of stages, in which user experience develops gradually as familiarity with interactive features and structure is gained.

The rest of this paper is structured in five sections. The next section provides a brief background. The third section describes a high-level system architecture and the adopted technologies as well as the systems under development. The fourth section provides a brief introduction to the educational aspects and the assessment methods for XRLabs. Finally, the last section summarizes the key points and sets out future work.

## 2 BACKGROUND

Onlabs is a standalone 3D virtual reality biology laboratory that provides a high-level realistic environment. It is developed by the Department of Science and Technology of the Hellenic Open University[1]. Onlabs simulates biology experiments like the microscopy procedure, the preparation of aqueous solutions and the protein electrophoresis. When using Onlabs the learner navigates in the virtual environment, operates various instruments and conducts biology experiments (Zafeiropoulos et al., 2014). Onlabs has been used as a supplementary educational material for students to be prepared for experiments in their real wet lab. The incorporation of Onlabs into the educational process already resulted in improvement in student learning outcomes, in terms both of subject understanding and laboratory skills acquisition (Paxinou et al., 2019). It is an educational application for users of different educational level and profession, which provides the opportunity to repeat the process of a laboratory experiment without any spatial, temporal and financial constraints, offering complete safety and privacy. The current version of Onlabs comes with three modes: the *Instruction Mode*, the *Evaluation Mode* and the *Experimentation Mode*. The combination of these tree modes offers the user a complete learning experience. A screenshot of the Onlabs' environment is presented in Figure 1.

## 3 XRLabs

In this section we describe the features of the XRLabs platform by highlighting the capabilities of the dynamic management of the educational content, the adopted mobile extended reality technologies and the

[1] https://sites.google.com/site/onlabseap/

Figure 1: Screenshot of Onlabs-Experimentation Mode.

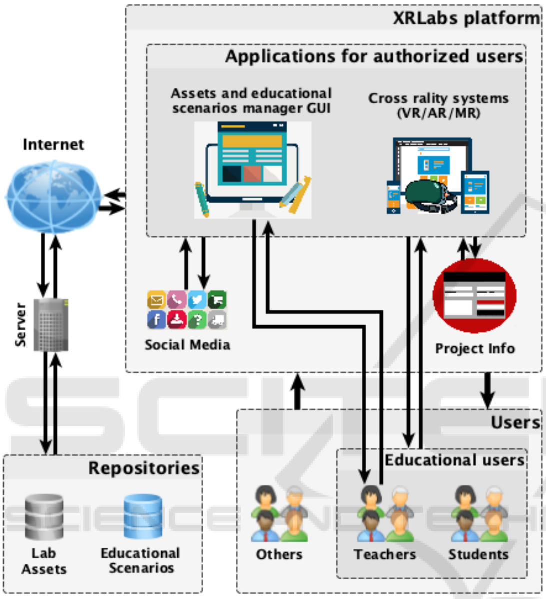


Figure 2: Architecture of the XRLabs Platform.

human-computer interaction based on hand gestures motion sensing system.

## 3.1 Integrated System Structure

Open linked data technologies (d'Aquin, 2016) pave the way towards the semantic Web of the future education by exploiting the abundance in data availability and enhancing the ongoing systems developments on the Web and computer technologies that bridge STEM laboratories and education with gaming. The XRLabs platform combines three main research areas of Semantic Web, namely: knowledge management in education, gamification and educational systems.

In order to manage dynamically the content (Kiourt et al., 2016) of the XR-reality environment, a web-based interface is being developed, based on link data technologies (de Vries and May, 2019). Figure 2 depicts the architecture of the XRLabs platform.

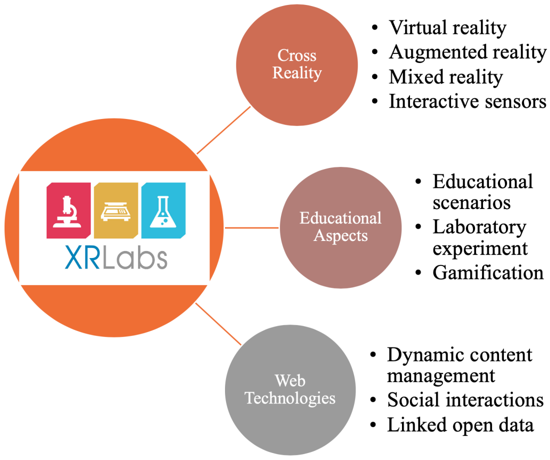


Figure 3: XRLabs Cutting-Edge Technologies/methods.

In this approach, all users (authenticated or not) have a basic limited access to the systems of the platform. On the other hand, authenticated users, like students and teachers, are provided with additional services.

The data interoperability of the platform is guaranteed by the open data technologies (Mouromtsev and d'Aquin, 2016) utilised by the repositories of XR-labs. The data transfer between the systems of XR-Labs and the external Web resources is being implemented using the JSON data-interchange format.

The main structure of XRLabs includes cutting-edge technologies and methodologies focusing on a user-friendly playful educational platform. For this reason, several innovative elements are combined to produce this environment, as shown in Figure 3.

## 3.2 Extended Reality Laboratory

One of the biggest challenges in XR applications design is finding the balance of mixing two totally different dimensions, the virtual and the physical. The challenge of merging virtual and physical worlds is has been addressed from different points of view and various disciplines, such as computer science, psychology, sociology and even science fiction, among others. XR allows the merging of physical and virtual worlds creating environments where physical and digital objects co-exist and interact in real-time (Tamura et al., 2001), and has been applied in various applications, ranging from entertainment and health to military training.

XR may have several similar definitions with few variations, but its main concept can be described as a form of "*mixed reality environment that comes from the fusion of . . . ubiquitous sensor/actuator networks and shared online virtual worlds*", to encompass all the possibilities of reality warping technology (Paradiso and Landay, 2009). Simply put, one may describe XR technologies as a combination of all reality technologies, such as VR (Burdea and Coiffet, 1993), AR (Azuma, 1997) and MR (Milgram and Kishino, 1994), including some additional physical tools (hardware, such as cameras, sensors, glasses etc.) (Paxinou et al., 018a; Mann et al., 2018) that enrich the interactivity. Within this framework users have the opportunity to interact with each other within a virtual world and get information from the real world, receiving thus an enhanced experience.

The name of the XRLabs platform [2] derives from the acronym XR (Extended Reality) and the word Labs (Laboratories). The platform enriches the Onlabs virtual environment with XR technologies, elevating the experience offered by the original system. XRLabs is an innovative platform that combines web technologies, XR technologies and educational approaches for the remote preparation of students in laboratory experiments with realistic simulation instruments and environments. XRLabs enhances the learning process by combining:

- the power of a digital literacy system,
- the pedagogical benefits of game-based learning,
- the interaction provided through the XR system with multiple users in a collaborative and/or competitive environment and
- the VR, AR and MR benefits that can contribute to *on the job training*.

XRLabs aims to be an integrated solution for students or professionals who want to be trained in laboratory exercises privately and at their own pace, as well as being able to interact with others. As any laboratory instrument, such as a microscope, has several manipulation functionalities, through which users take measurements, detailed descriptions of these functionalities can be effectively presented through AR technologies. Figure 4 presents a screenshot of the AR elements of XRLabs, where a real microscope augmented with digital descriptive data is shown.

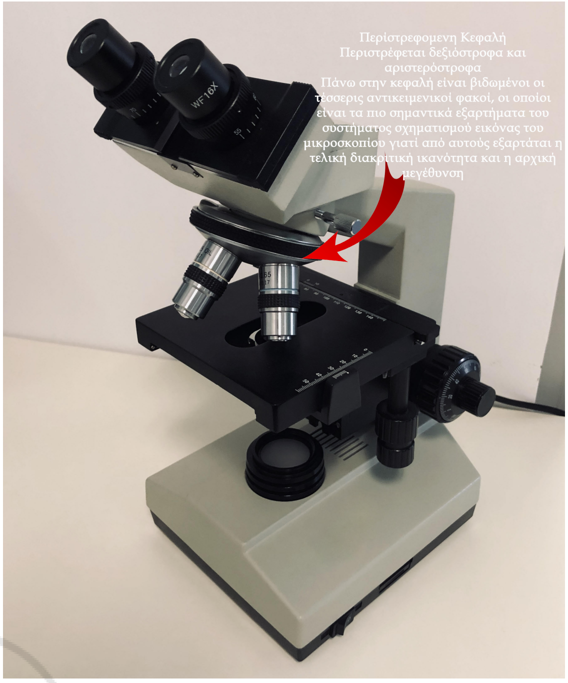


Figure 4: AR Applied on a Real Microscope.

## 3.3 Motion Sensing System

Real-time interaction with XR environments using motion sensors' technologies is one very active field and often included in educational processes (Bratitsis and Kandroudi, 2014; Liang et al., 2019) as well as in many other fields such as the industry (Nousias et al., 2019; Lalos et al., 2018; Gardelis. et al., 2018), health etc. Realistic interaction is achieved through a variety of input devices (Bekele et al., 2018). An example of the XRLabs platform equipped with motion sensing controllers (tangible input devices) is shown in Figure 5, where youngsters interact with an object of a virtual laboratory.

Figure 5: Interaction with Motion Sensing Controllers.

Tangible input devices, such as gloves, gamepads, joysticks, mice, touch screens, wearables and wands are very effective interaction interfaces, with important positive impact on education (O'Malley and Stanton Fraser, 2004). On the other hand the utilization of contact-free motion sensing controllers (motion track-

[2] http://xrlabs.eu

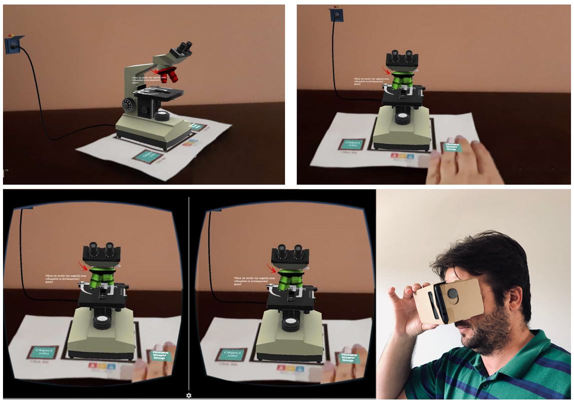

Figure 6: XRLabs in Action through a Smartphone.

ing systems) (Bachmann et al., 2014), input devices such as gesture sensors (e.g. Leap Motion), haptic sensors and cameras, instead of tangible motion sensing controllers, can be much more effective, since users feel more comfortable when their hands are free. In addition, the handling of virtual objects (in our case laboratory equipment) with bare hands is much more realistic and allows to encounter higher quality immersive experiences (Pavaloiu, 2016; Ebner and Spot, 2016). Camera-based motion tracking methods are popular and widely exploited, despite their lack of high accuracy, due to the low-cost of the required equipment.

In order to increase the wide acceptance and exploitation of the XRLabs platform, the XR elements of the system are based on mobile device capabilities, such as those offered by modern smartphones. Figure 6 depicts the XR elements during a microscopy training session, in which a 3D model of a microscope is shown on a real desk; additional descriptive data are superimposed over each part of the instrument. Each interactive component of the instrument has two states. The first is the description state during which information about the component is displayed and the component is highlighted with red colour, as shown in Figure 6 top-right. The second state is the manipulation part, during which the component is highlighted with green colour and can be interacted with, as shown in Figure 6 top-right. During the manipulation stage, two virtual buttons are placed on the opposite sides of the instrument, which enables to handle the active component with simple hand gestures. The real-time interaction is based on the smartphone's hardware. Figure 6 bottom-left, shows an example of a stereoscopic view, displayed by the system. The user just needs to insert a smartphone in a low-cost VR headset (like the Google cardboard – see Figure 6 bottom-right), install the appropriate application, and automatically experience the AR/MR content over the appropriate marker on the desk. By using hand gestures over the virtual buttons, the user interacts with the laboratory instrument.

# 4 EDUCATIONAL ASPECTS AND ASSESSMENT

Simulations and gamification are extensively applied in higher education as an attempt to improve students' learning experience in Biology, Chemistry, Astronomy, Geometry, Cultural Heritage, etc. (Garzón et al., 2017; Sypsas et al., 2019). Based on the relevant literature, virtual laboratories demonstrate a positive effect on students' cognitive load, skills development and motivation (Xu et al., 2018).

## 4.1 Educational Activities through Gamification

The gamification aspects of XRLabs are offered by the development of educational scenarios, playful and educational rules, storytelling, content personalization elements, strategies, timers, rewards, badges, leaderboards and many other elements that increase the engagement and the motivation of the learners, without overlooking the main purpose of the system, which is education. Within this concept the XR environment is obtaining the sense of a playful educational system. For the purpose of representing the meaning and the value of gamification, an interesting formula has been presented in (Nicholson, 2012) to show the association between the terms game, play, goals and structure:

$$Game = Play + Goals + Structure \quad (1)$$

By following the main idea and the principals of gamification XRLabs aims to address the following challenges:

- learner engagement
- remote practice in laboratory equipment
- performance and skill assessment

The features that provide dynamical content management, provide trainers important capabilities for the customization of the educational scenarios/procedures or the development of new ones. Additionally, trainers may exploit the XR system as a laboratory procedure presentation that offers enhanced experience through a screen sharing plugin of the mobile device. This leads to a worldwide real-time connection among trainers and learners. On the other hand, the exploitation of XRLabs in educational processes focuses on four different stages:

- Home practicing: as a preparation tool before the interaction with the physical laboratory instruments.
- Instrument usage enhancement: during the real experiment in the laboratory with the help of the supervisors.
- Learners' assessment: evaluation in laboratory procedures or instrument usage through automated evaluation modes.
- Continuous knowledge update/lifelong learning: without any restrictions, out of courses or training sessions.

### 4.2 Learners Evaluation

The evaluation of learners by non-automated methods (systems), is a very challenging and multidimensional procedure (Wang, 2018), usually relating to learning analytics. In order to ensure the high quality in science teaching, educational XR applications are being assessed based on the learners' ability to respond to the requirements of science courses. Learners in this context are evaluated by real-time evaluation algorithm using conceptual tests, practical examinations, questionnaires and combinations. The conceptual tests are based on Web-based assessment technologies, for fast collection and analysis of data, or classroom written paper tests. Both are to grade learners' improvement regarding a specific science topic, based on a pre-test, which sets the baseline knowledge and preset criteria (Makransky et al., 2016). The practical examinations intent on evaluating the learners' obtained experimentation skills. Through the questionnaires, that usually have a 5 or 7-point Likert scale, the learners' express their opinion on satisfaction, interest, confidence and understanding regarding the introduction of the XR educational application in the teaching procedure (Paxinou et al., 018b).

In order to assess XRLabs, a combination of the above strategies will be used to compose a specially designed educational scenario adapted to XR technology. Students with previous knowledge or students with minimum or zero training in the scientific principles and techniques will join the control and experimentation groups. Main objective is to investigate whether students, who use XRLabs as a complement to more traditional learning methods, gain easier science knowledge and experimentation skills or they are cognitively overloaded by the large amount of information, the multiple technological devices they are required to use, and the complex tasks they have to deal with.

## 5 CONCLUSIONS

The aim of this paper is to introduce a dynamical interactive Extended Reality environment as an open technological framework to allow the easy creation of educational procedures with simulated STEM laboratories for all levels of education. Interactive XR laboratories, are convenient, safe, economical, rapid, flexible and user-friendly educational tools that challenge, engage and prepare students for their real scientific experiments. Apparently, they are an inevitable component of remote education and distance learning.

The expected societal impact of XRLabs is rather significant. The students are developing a positive attitude towards the laboratory education. Also, their safety is improved, and also their awareness of the laboratory hazards (including equipment and consumables). The laboratory equipment is protected from misuse and malfunctioning due to the multiple educational repetitions of the experiments. In addition, the cost reduction in terms of the usage of consumables can be significant. All these benefits give educational institutions the opportunity to invest on new educational products and scientific directions towards the improvement of the quality of life.

In the future we plan to develop a suite of tactile and visual experience optimization for mobile and standalone XR educational systems. More specifically, the suite will comprise of: (i) an AR SDK for supporting illumination consistency and device-perspective rendering mechanisms, which will be integrated with a smart sensing module in order to allow robust pose estimation against sensing drifts and occlusions that occur in complex motion patterns and (ii) novel ultrasonic based hardware solutions and a novel software SDK for offering emerging haptics to virtual objects, developing touchable holographic interfaces, and augmenting gesture control with natural tactile feedback. In addition, development of an upgrade system exploiting markerless XR techniques to eliminate the need of special printed image markers is also in the future plans.

## ACKNOWLEDGEMENTS

This work is supported by the project XRLABS - Virtual laboratories using interactive technologies in virtual, mixed and augmented reality environments (MIS 5038608) implemented under the Action for the Strategic Development on the Research and Technological Sector, co-financed by national funds through the Operational programme of Western Greece 2014-

2020 and European Union funds (European Regional Development Fund)

## REFERENCES


Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoper. Virtual Environ.*, 6(4):355–385.

Bachmann, D., Weichert, F., and Rinkenauer, G. (2014). Evaluation of the leap motion controller as a new contact-free pointing device. *Sensors*, 15(1):214–233.

Becerra., D. A. I., Quispe., J. A. H., Aceituno., R. G. A., Vargas., G. M. P., Zamora., F. G. F., Mango., J. L. H., Figueroa., G. P. A., Vizcarra., A. A. P., and Chana., J. W. T. (2017). Evaluation of a gamified 3d virtual reality system to enhance the understanding of movement in physics. In *Proceedings of the 9th International Conference on Computer Supported Education - Volume 1: CSEDU,*, pages 395–401. INSTICC, SciTePress.

Bekele, M. K., Pierdicca, R., Frontoni, E., Malinverni, E. S., and Gain, J. (2018). A survey of augmented, virtual, and mixed reality for cultural heritage. *J. Comput. Cult. Herit.*, 11(2).

Bogusevschi., D. and Muntean., G. (2019). Water cycle in nature – an innovative virtual reality and virtual lab: Improving learning experience of primary school students. In *Proceedings of the 11th International Conference on Computer Supported Education - Volume 1: CSEDU,*, pages 304–309. INSTICC, SciTePress.

Bonde, M. T., Makransky, G., Wandall, J., Larsen, M. V., Morsing, M., Jarmer, H., and Sommer, M. O. (2014). Gamified laboratory simulations motivate students and improve learning outcomes compared with traditional teaching methods. *Nature Biotechnology*, 32(7):694–697.

Bratitsis, T. and Kandroudi, M. (2014). Motion sensor technologies in education. *EAI Endorsed Transactions on Serious Games*, 1(2).

Brown, S. and Vaughan, C. (2010). *Play: How it Shapes the Brain, Opens the Imagination, and Invigorates the Soul*. J P Tarcher/Penguin Putnam.

Burdea, G. and Coiffet, P. (1993). *Virtual Reality Technology*. NY: John Wiley & Sons, Inc.

d'Aquin, M. (2016). *On the Use of Linked Open Data in Education: Current and Future Practices*, pages 3–15. Springer International Publishing, Cham.

de Vries, L. E. and May, M. (2019). Virtual laboratory simulation in the education of laboratory technicians–motivation and study intensity. *Biochemistry and Molecular Biology Education*, 47(3):257–262.

Ebner, M. and Spot, N. (2016). *Game-Based Learning with the Leap Motion Controller*, pages 555–565. IGI Global.

Estapa, A. and Nadolny, L. (2015). The effect of an augmented reality enhanced mathematics lesson on student achievement and motivation. *Journal of STEM Education*, 16(3):40.

Ferrer-Torregrosa, J., Torralba, J., Jimenez, M. A., García, S., and Barcia, J. M. (2015). Arbook: Development and assessment of a tool based on augmented reality for anatomy. *Journal of Science Education and Technology*, 24(1):119–124.

Gardelis., K., Lalos., A. S., and Moustakas., K. (2018). Development of an eco-driving simulation training system with natural and haptic interaction in virtual reality environments. In *Proceedings of the 13th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications - Volume 3 IVAPP: HUCAPP,*, pages 94–101. INSTICC, SciTePress.

Garzón, V., Carlos, J., Magrini, M. L., and Galembeck, E. (2017). Using augmented reality to teach and learn biochemistry. *Biochemistry and Molecular Biology Education*, 45(5):417–420.

Heradio, R., de la Torre, L., Galan, D., Cabrerizo, F. J., Herrera-Viedma, E., and Dormido, S. (2016). Virtual and remote labs in education: A bibliometric analysis. *Computers & Education*, 98:14 – 38.

Karakasidis, T. (2013). Virtual and remote labs in higher education distance learning of physical and engineering sciences. In *2013 IEEE Global Engineering Education Conference (EDUCON)*, pages 798–807.

Kiourt, C., Koutsoudis, A., and Pavlidis, G. (2016). Dynamus: A fully dynamic 3d virtual museum framework. *Journal of Cultural Heritage*, 22:984 – 991.

Lalos, A. S., Nousias, S., and Moustakas, K. (2018). Gamecar: Gamifying selfmanagement of eco-driving. *ERCIM News 115 (Oct. 2018): 46-47*.

Lalos, S., Kiourt, C., Kalles, D., and Kalogeras, A. (2020). Personalized interactive edutainment in extended reality (xr) laboratories. *ERCIM News, Educational Technology*, 120:29–30.

Liang, J., Su, W., Chen, Y., Wu, S., and Chen, J. (2019). Smart interactive education system based on wearable devices. *Sensors*, 19(15).

Makransky, G., Thisgaard, M. W., and Gadegaard, H. (2016). Virtual simulations as preparation for lab exercises: Assessing learning of key laboratory skills in microbiology and improvement of essential non-cognitive skills. *PLoS One*, 11(6).

Mann, S., Furness, T., Yuan, Y., Iorio, J., and Wang, Z. (2018). All reality: Virtual, augmented, mixed (x), mediated (x,y), and multimediated reality.

Milgram, P. and Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, 12:1321–1329.

Mouromtsev, D. and d'Aquin, M. (2016). *Open Data for Education: Linked, Shared, and Reusable Data for Teaching and Learning*. Springer.

Nicholson, S. (2011). Making gameplay matter : Designing modern educational tabletop games. *Knowledge Quest*, 40(1):60–65.

Nicholson, S. (2012). Strategies for meaningful gamification: Concepts behind transformative play and participatory museums. In *Presented at Meaningful Play 2012*. Lansing, Michigan.

Nousias, S., Tselios, C., Bitzas, D., Amaxilatis, D., Montesa, J., Lalos, A. S., Moustakas, K., and Chatzigiannakis, I. (2019). Exploiting gamification to improve eco-driving behaviour: The gamecar approach. *Electronic Notes in Theoretical Computer Science*, 343:103 – 116. The proceedings of AmI, the 2018 European Conference on Ambient Intelligence.

O'Malley, C. and Stanton Fraser, D. (2004). Literature review in learning with tangible technologies. Workingpaper, FutureLab. Report 12 ID number: 0-9548594-2-1.

Paradiso, J. A. and Landay, J. A. (2009). Guest editors' introduction: Cross-reality environments. *IEEE Pervasive Computing*, 8(3):14–15.

Pavaloiu, B. (2016). Leap motion technology in learning. In *The 7th International Conference Edu World 2016*.

Paxinou, E., Karatrantou, A.and Kalles, D., Panagiotakopoulos, C., and Sgourou, A. (2018b). A 3d virtual reality laboratory as a supplementary educational preparation tool for a biology course. *European Journal of Open, Distance and E-Learning*.

Paxinou, E., Panagiotakopoulos, C. T., Karatrantou, A., Kalles, D., and Sgourou, A. (2019). Implementation and evaluation of a three-dimensional virtual reality biology lab versus conventional didactic practices in lab experimenting with the photonic microscope. *Biochemistry and Molecular Biology Education*.

Paxinou, E., Zafeiropoulos, V., Sypsas, A., Kiourt, C., and Kalles, D. (2018a). Assessing the impact of virtualizing physical labs. In *Proceeding of the 27th EDEN Annual Conference, European Distance and E-Learning Network*, pages 17–20.

Pena, Rios, A. (2016). *Exploring mixed reality in distributed collaborative learning environments*. (Doctoral dissertation): School of Computer Science and Electronic Engineering, University of Essex.

Reigeluth, M. C. (1999). *Instructional-design theories and models: An overview of their current statues*. Lawrence Erlbaum Associates Inc.

Seaborn, K. and Fels, D. I. (2015). Gamification in theory and action: A survey. *International Journal of Human-Computer Studies*, 74:14 – 31.

Shin., J., Jin., K., and Kim., S. (2019). Investigation and evaulation of a virtual reality vocational training system for general lathe. In *Proceedings of the 11th International Conference on Computer Supported Education - Volume 2: CSEDU,*, pages 440–445. INSTICC, SciTePress.

Sypsas, A., Kiourt, C., Paxinou, E., Zafeiropoulos, V., and Kalles, D. (2019). The educational application of virtual laboratories in archaeometry. *International Journal of Computational Methods in Heritage Science*, 3(1):1–19.

Tamura, H., Yamamoto, H., and Katayama, A. (2001). Mixed reality: future dreams seen at the border between real and virtual worlds. *IEEE Computer Graphics and Applications*, 21(6):64–70.

Wang, T. (2018). Developing a web-based assessment system for evaluating examinee's understanding of the procedure of scientific experiments. *Eurasia Journal of Mathematics, Science and Technology Education*, 14(5):1791–1801.

Xu, X., Allen, W., Miao, Z., Yao, J., Sha, L., and Chen, Y. (2018). Exploration of an interactive "virtual and actual combined" teaching mode in medical developmental biology. *Biochemistry and Molecular Biology Education*, 46(6):585–591.

Zafeiropoulos, V., Kalles, D., and Sgourou, A. (2014). Adventure-style game-based learning for a biology lab. In *2014 IEEE 14th International Conference on Advanced Learning Technologies*, pages 665–667.