International Review of Research in Open and Distributed Learning

OXREF: Open XR for Education Framework

Ishan Sudeera Abeywardena

Volume 24, Number 3, August 2023

URI: https://id.erudit.org/iderudit/1106778ar
DOI: https://doi.org/10.19173/irrodl.v24i3.7109

See table of contents

Publisher(s)

Athabasca University Press (AU Press)

ISSN

1492-3831 (digital)

Explore this journal

Cite this article

Abeywardena, I. (2023). OXREF: Open XR for Education Framework. *International Review of Research in Open and Distributed Learning*, *24*(3), 185–206. https://doi.org/10.19173/irrodl.v24i3.7109

Article abstract

Extended reality (XR), which encompasses virtual reality (VR), augmented reality (AR), and mixed reality (MR), offers powerful affordances for improving teaching and learning experiences in a post-pandemic world. Increasingly, many governments and institutions around the world are making major investments in XR technologies to prepare education systems for the future. However, many of these investments remain isolated pilot projects which, while they attest to the potential of XR in education, are unlikely to be scaled up due to lack of sustainability and collaboration. Based on literature and empirical evidence, I have identified major barriers to the wider adoption of XR in education, including the lack of (a) open content, tools, and skills; (b) sound pedagogy and instructional design; and (c) scalability and sustainability. As a potential solution, I introduce the Open XR for Education Framework (OXREF), an empirical framework that proposes a holistic solution to XR object creation, implementation, and deployment, while covering pedagogical, technological, and policy perspectives. The contribution of the OXREF is its ability to build fit-for-purpose XR experiences in a scalable, sustainable, and collaborative manner while promoting openness, accessibility, equity, and reuse. The novelty of the proposed framework is its use of open educational resources (OER), open educational practices (OEP), as well as free and open-source software (FOSS) tools and platforms. Its cloud-based infrastructure and open licenses support viable operationalization strategies that can be implemented by educational institutions and governments.

International **R**eview of **R**esearch in **O**pen and **D**istributed **L**earning
Volume 24, Number 3

August – 2023

OXREF: Open XR for Education Framework

Ishan Sudeera Abeywardena
University of Waterloo

Abstract

Extended reality (XR), which encompasses virtual reality (VR), augmented reality (AR), and mixed reality (MR), offers powerful affordances for improving teaching and learning experiences in a post-pandemic world. Increasingly, many governments and institutions around the world are making major investments in XR technologies to prepare education systems for the future. However, many of these investments remain isolated pilot projects which, while they attest to the potential of XR in education, are unlikely to be scaled up due to lack of sustainability and collaboration. Based on literature and empirical evidence, I have identified major barriers to the wider adoption of XR in education, including the lack of (a) open content, tools, and skills; (b) sound pedagogy and instructional design; and (c) scalability and sustainability. As a potential solution, I introduce the Open XR for Education Framework (OXREF), an empirical framework that proposes a holistic solution to XR object creation, implementation, and deployment, while covering pedagogical, technological, and policy perspectives. The contribution of the OXREF is its ability to build fit-for-purpose XR experiences in a scalable, sustainable, and collaborative manner while promoting openness, accessibility, equity, and reuse. The novelty of the proposed framework is its use of open educational resources (OER), open educational practices (OEP), as well as free and open-source software (FOSS) tools and platforms. Its cloud-based infrastructure and open licenses support viable operationalization strategies that can be implemented by educational institutions and governments.

Keywords: OXREF, open XR, XR for education, XR framework, extended reality, XR scalability, XR sustainability, VR, AR, OER, OEP, open licenses

Introduction

Extended reality (XR) is used as an inclusive term to encapsulate the three main types of immersive technologies—virtual reality (VR), augmented reality (AR), and mixed reality (MR). XR can be referred to as a collection of experiences which blur the line between real and virtual worlds using immersive visuals, audio, and haptic cues (Alizadehsalehi et al., 2020).

Steuer (1992) provided an early definition of VR, namely that "virtual reality make reference to a particular technological system. This system usually includes a computer capable of real-time animation, controlled by a set of wired gloves and a position tracker, and using a head-mounted stereoscopic display for visual output" (p. 74). In a more modern definition, Fernandez (2017) indicated that VR technology "provides the user with the opportunity to be immersed in a programmed environment that simulates a reality" (p. 1).

AR has been defined as technology which combines real and virtual worlds, wherein the real world is supplemented with computer-generated virtual objects in real-time (Khan et al., 2019). MR comprises three important aspects: (a) combining the real-world object with the virtual object, (b) real-time interaction, and (c) mapping between the virtual object and the real-world object so that they interact with each other (Rokhsaritalemi et al., 2020).

The Gartner Hype Cycle for Education (Yanckello, 2022) placed XR and immersive technology at the beginning of the trough of disillusionment, which suggested it will become mainstream within the next 5 to 10 years. Increasingly, many governments and institutions around the world have been making major investments in XR technologies and preparing education systems for the future (Schwaiger, 2021). EDUCAUSE (2018) has stated that "new and more affordable XR technologies provide promising directions and opportunities to immerse learners in the curriculum, offering deeper and more vivid learning experiences and extending the learning environment" (para.1). Another example from United Nations Virtual Reality (UNVR, 2017) indicated that "with the support of the UN SDG Action Campaign, delegates and OECD staff were able to immerse themselves in the world of Sidra, a 12-year-old Syrian Refugee living in Za'tari refugee camp in Jordan" (para. 3). According to the UNESCO Mahatma Gandhi Institute of Education for Peace and Sustainable Development (MGIEP):

> It definitely beats just using textbooks. MGIEP believes in transforming education for building peaceful and sustainable societies. It sees immersive experiences such as VR as an integral part of socio emotional learning for our younger generations as they face 21st century challenges to build a peaceful and sustainable planet. (India Blooms News Service, 2017, para. 11)

However, many of these investments remain isolated pilot projects. As such, they provide a glimpse into what the potential future of education could be, but one that is unlikely due to issues of scalability, sustainability, and a lack of institutional collaboration (Doolani et al., 2020; Garcia Estrada & Prasolova-Førland, 2022).

At an institutional level, pedagogy and instructional design remain barriers to teaching and learning using the XR medium. According to Yang et al. (2020) "while XR is getting used more in education, many XR practitioners (e.g., technology designers and developers) may not be intimately familiar with educational theory and instructional design; so most reviews could have limited use in practice" (p. 2). Lai and Cheong (2022) considered the lack of alignment between pedagogy and technology infrastructure to be a major barrier to XR adoption. Further, they stated that lack of (a) teacher training, (b) educational experience, (c) conceptual foundation, (d) educational research, and (e) institutional support were specific contributing factors.

Lack of technical skills in using XR tools and technologies has been cited as another barrier to wider adoption. According to a Norwegian study "it takes time and effort to learn the setup, control, and navigate the software, and even more time to learn to customize it to suit one's individual teaching" (Simon-Liedtke et al., 2022, p. 552). In the same study, the authors stated that due to high workloads, educators were unable to dedicate time to learn, experiment, and practice XR skills during normal working hours.

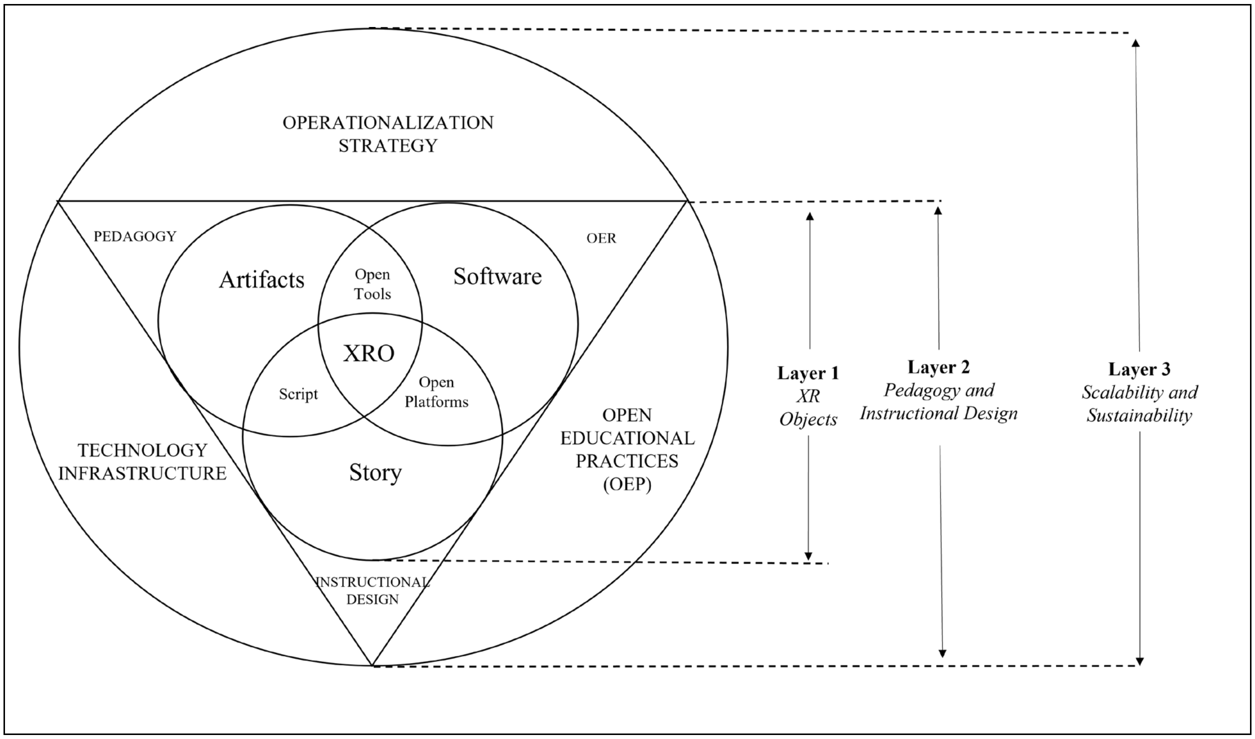
Based on literature and empirical evidence, I have identified that the lack of (a) open content, tools, and skills; (b) sound pedagogy and instructional design; and (c) scalability and sustainability have been major barriers to the wider adoption of XR in education. As a potential solution, I introduced the Open XR for Education Framework (OXREF), an empirical framework that proposes a holistic solution to XR object creation, implementation, and deployment, while covering pedagogical, technological, and policy perspectives. The contribution of the OXREF is its ability to build fit-for-purpose XR experiences in a scalable, sustainable, and collaborative manner that promotes openness, accessibility, equity, and reuse. The novelty of the proposed framework is its use of open educational resources (OER), open educational practices (OEP), as well as free and open-source software (FOSS) tools and platforms. Its cloud-based infrastructure and open licenses support viable operationalization strategies that can be implemented by educational institutions and governments.

The Open XR for Education Framework in Detail

The OXREF comprises three layers: (a) open XR object creation, (b) pedagogy and instructional design input, and (c) scalability and sustainability for a holistic approach to creating fully fledged open XR experiences, from conceptualization to deployment and beyond. The three layers of the OXREF are shown in Figure 1.

Figure 1

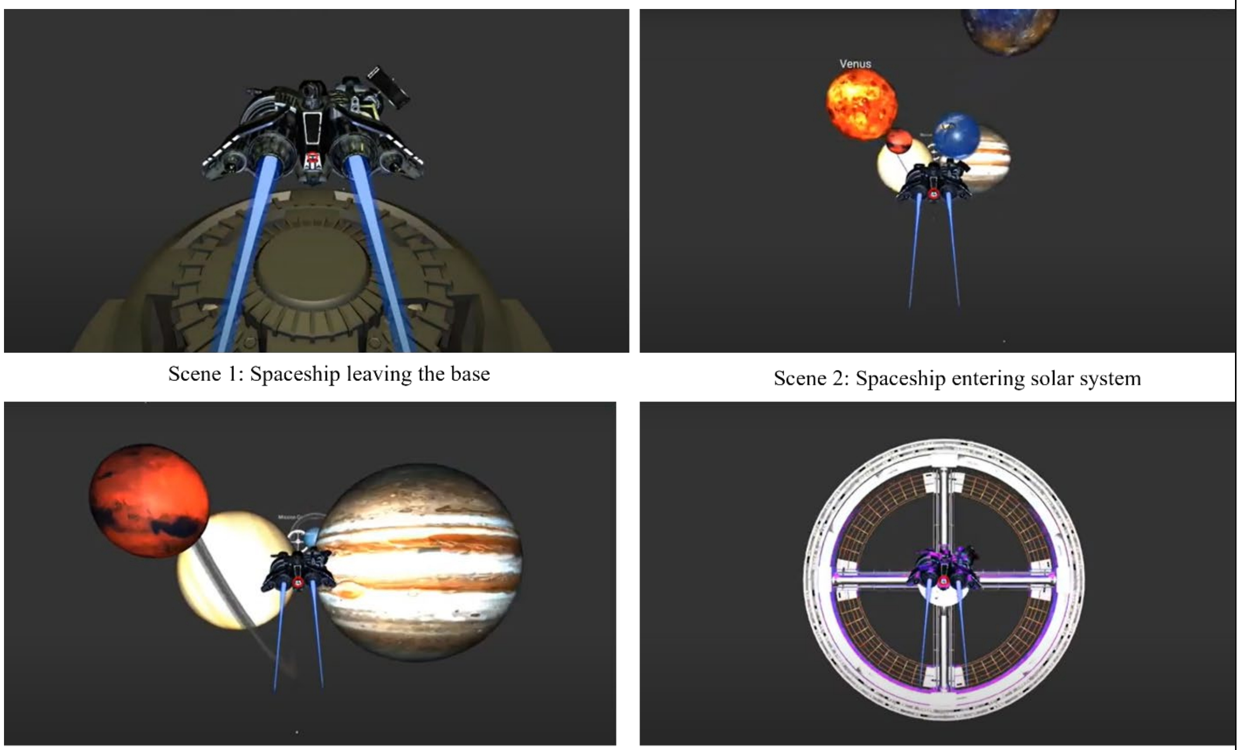
The Open XR for Education Framework (OXREF)



For the purposes of this paper, I will explore each layer of this empirical framework using the Voyager VR simulation (The Shady Bunch, 2018) (The Shady Bunch, 2018)as an example. An overview of the Voyager VR simulation is shown in Figure 2.

Figure 2

The Four Main Scenes of the Voyager VR Simulation



Scene 1: Spaceship leaving the base

Scene 2: Spaceship entering solar system

Scene 3: Spaceship flying through the solar system

Scene 4: Spaceship docking at the space station

Note. Adapted from "Voyager Virtual Reality (VR) Journey Through Space" by The Shady Bunch, 2018, (https://youtu.be/Tn1TqYHPrUM). CC BY 4.0.

The Voyager is a simple WebVR simulation bult using A-Frame, which is a FOSS VR development platform using HTML5 and JavaScript, originally created by Mozilla VR. The simulation depicts an animated spaceship leaving a base, flying through space and the solar system, and docking at a space station at the end of the journey. A video of the Voyager VR simulation can be found on YouTube. Although I have used a VR simulation to explain the various components of the framework, the OXREF is applicable to all XR including VR, AR, and MR.

Open XR Object Creation

Layer 1 of the OXREF deals with creating individual XR objects including a story, artifacts, and design/development software. These, in turn, intersect to inform a script, open tools, and open platforms for the XR objects. Layer 2 provides the pedagogical and instructional design for the XR development within the guidelines of OER, which include reuse, revision, remixing, redistribution, and retention (Abeywardena, 2017). It should be noted that Layers 1 and 2 interact in a complementary manner throughout the XR development process.

The Story

The development of all XR objects begins with the story. The story details the requirements of the XR simulation with respect to the specific teaching and learning scenario or need. In the case of the Voyager VR simulation, the story provided learners a glimpse into the various shapes, colors, and sizes of the planets in our solar system.

The Script

Based on the story, a script (Mourchid et al., 2018) is created to identify how the story can be narrated in a virtual environment achieving the intended competencies or learning outcomes. The main components of the script are (a) who? (the characters); (b) where? (the locations); (c) what? (the subjects talked about); (d) when? (the scenes); and (e) how? (the process to achieve the story). The how? component is formulated using the artifacts and the software.

The script for the Voyager VR simulation contained the following elements:

- Who? Spaceship, base station, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and docking station.
- Where? Outer space.
- What? Various shapes, colors, and sizes of the planets in our solar system.
- When? (a) Scene 1: spaceship leaving the base; (b) Scene 2: spaceship entering the solar system; (c) spaceship flying through the solar system; and (d) spaceship docking at the space station.

Pedagogy and Instructional Design

Pedagogical and instructional design input helps shape the script in alignment with the expected competencies or learning outcomes. From a pedagogical perspective, the XR simulations should foster (a) self-empowerment/self-efficacy, (b) critical thinking and decision making, (c) technical knowledge and problem solving, and (d) inclusive excellence and community of practice (Guilbaud et al., 2021). From an instructional design perspective, the XR simulations should consider several key factors (Meccawy, 2022) as detailed in Table 1.

Table 1

Instructional Design Factors to be Considered in XR Simulations

Instructional design factor	Questions to be addressed in the XR experience
Technical expertise	How technically adept are the team members?
	How fast could they learn a new programming language or navigate a new developing environment?
Time	How quickly is this immersive learning environment needed?

Budget	How much is management willing to invest in creating an immersive learning environment? Would creating an in-house solution be cheaper than subscribing to a readily available solution?
Scalability (number of participants)	What is the cost per classroom? Is there a maximum user capacity limit? What is the feasibility/cost of expanding beyond maximum capacity?
Level of control	What are the trade-offs when using an off-the-shelf solution compared to developing in house?
Configuration and maintenance	What investments are needed in terms of funds, time, resources, and capacity building to configure and maintain the solutions?
Availability of suitable XR learning content	Is there learning content already available which can be adapted to this learning scenario? Are the XR learning content compliant with accessibility requirements and guidelines?
Pedagogical alignment	Do the XR content align with existing curriculum? Will introducing XR yield the desired learning outcomes? Do we have the depth of knowledge in the subject matter in addition to software design/development skills? Is the XR solution designed for educational purposes rather than a retrofitted or modified industry solution?
Security and privacy	Does the XR solution deal with sensitive information? Does the XR solution comply with national, provincial, and institutional privacy and security requirements?
Degree of immersion and output tools	Does the XR simulation need to be fully immersive or will it achieve the same learning outcome using partially or non-immersive approaches? Will students need special equipment (e.g., VR headsets, VR controllers, smartphones) to access the content? Who will provide the output tools for students to interact with the content? Are there accessibility, inclusivity, and equity concerns in using a particular output tool?

Note. Adapted from “Creating an Immersive XR Learning Experience: A Roadmap for Educators,” by M. Meccawy, 2022, *Electronics, 11*(21) (https://doi.org/10.3390/electronics11213547). CC BY 4.0.

Artifacts and Software

The artifacts of an XR simulation include (a) 3D modeling such as wireframes and virtual objects; (b) 2D graphic designs such as textures and backgrounds; (c) video elements such as 360-degree videos; (d) animations; and (e) audio content such as sound effects and voiceovers, among others.

The artifacts for the Voyager VR simulation included the following:

- 3D models—spaceship, base station, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and docking station.
- 2D graphics—textures for the planet surfaces, planet names, and background space.
- Video elements—not used.
- Animations—rocking motion of the spaceship, exhaust coming out of the spaceship engines, spaceship flying forward in space, and flashing lights at docking station.
- Audio—spaceship engine noise and voiceover narrations.

When considering software, there are numerous commercial tools and platforms which can be used to create artifacts and XR objects. However, to develop open XR content which can be reused, revised, remixed, redistributed, and retained in keeping with the freedoms allowed through OER, using FOSS should be considered the primary option (Abeywardena, 2012). While selecting the FOSS tools and platforms to be used for a particular project, ALMS parameters (Abeywardena et al., 2012) consisting of (a) Access to editing tools, (b) Level of expertise required to revise or remix, (c) ability to Meaningfully edit, and (d) Source file access should be used to identify the most fit-for-purpose tools based on the project's requirements (Table 1).

Scalability and Sustainability

Layer 3 deals with scalability and sustainability, which remain major barriers to the wider adoption of modern educational technologies (Renz & Hilbig, 2020), through the lenses of OEP, technology infrastructure, and operationalization strategy. Although there is significant interest from governments and institutions which have given rise to exemplary pilot XR project, the majority remain as pilot projects and do not scale beyond their original scope (Kluge et al., 2022). Furthermore, Kluge et al. (2022) stated that ongoing funding, lack of IT support, integration issues, and non-sustainable implementation strategies were the major barriers for ongoing use of XR. According to Wang et al. (2020) "currently, there is still lack of global collaboration on the research and development of AR and VR tools and applications" (p. 542). A potential solution to these issues is the adoption of OEP including (a) supporting the production and (re)use of OER through institutional policies; (b) promoting innovative pedagogical models; (c) open technologies; (d) open licensing; and (e) respecting and empowering learners as co-producers on their lifelong learning path (Koseoglu & Bozkurt, 2018). Many case studies from the OER movement have attested to the ability of OEP to increase scalability and sustainability in education (Cronin, 2017; Friesen, 2009; MacKinnon et al., 2016; McGreal, 2017; Tlili et al., 2021). Figure 3 provides an XR operationalization readiness checklist for educational institutions, adapted from Abeywardena (2017) and guided by the principles of OEP.

Figure 3

XR Operationalization Readiness Checklist for Educational Institutions

Process	Stakeholder						Mainstreaming task
	Management	Academic staff	Pedagogy, ID and EdTech	Library	Systems development	Learners	
1. Change in mindset	✓	✓	✓	✓	✓	✓	1.1 Decided to produce and/or (re)use XR for teaching and learning? 1.2 Is XR a good fit-for-purpose in my institution? 1.3 Is open good?
2. Build capacity		✓	✓	✓	✓	✓	2.1 What are XR and XR concepts? 2.2 What are the types of XR? 2.3 What is open and accessible XR? 2.4 What is copyright and open licensing? 2.5 What FOSS tools, technologies, and platforms are available for developing XR? 2.6 How to create, reuse, revise, remix, and retain XR?
3. Strategize	✓	✓	✓	✓	✓	✓	3.1 Identified the need for XR in terms of cost, quality, and access? 3.2 Identified short-, medium-, and long-term goals for XR? 3.3 Identified representatives from each stakeholder group for task teams?
4. Adopt an open license	✓	✓	✓	✓		✓	4.1 How open is the institution? 4.2 How open are current learning content? 4.3 Allow commercial use? 4.4 Enforce ShareAlike? 4.5 Allow derivatives? 4.6 No rights reserved?
5. Technology infrastructure	✓			✓	✓		5.1 Have sufficient technology infrastructure? 5.2 Have sufficient technical personnel? 5.3 Invest in cloud-based technologies and services?

								5.4 Setup a FOSS repository?
6.	Policy	✓						6.1 Adopted an institutional XR policy? 6.2 Updated HR policies to recognize and reward XR related activities? 6.3 Recognized additional work in integrating XR into teaching and learning? 6.4 Made the integration of XR a key performance indicator (KPI)? 6.5 Developed a system for remuneration and encouragement? 6.6 Mainstreamed open educational practices?
7.	Practice		✓	✓	✓	✓	✓	7.1 Which courses will use XR? 7.2 Developed a systematic approach to integrating XR into learning content? 7.3 Formed XR development teams? 7.4 Identified XR fit-for-purpose in terms of competencies/learning outcomes? 7.5 Developed pilot XR content? 7.6 Successfully integrated XR into teaching and learning scenario? 7.7 Built a catalogue of reusable open XR objects?
8.	Quality assurance (QA)		✓	✓	✓	✓	✓	8.1 Formed an XR QA team for teaching and learning content? 8.2 Developed procedures for systematic software quality assurance (SQA) of the XR content? 8.3 Is this content suitable for our learners (user acceptance testing)? 8.4 Is it pedagogically sound? 8.5 Is it open and accessible? 8.6 Do we have ongoing tech support? 8.7 Is it scalable and sustainable beyond this implementation?
9.	Competencies and learning outcomes		✓	✓			✓	9.1 Have strategy for assessing XR content against competencies/learning outcomes? 9.2 Are XR based assessments correctly mapped against the learning outcomes? 9.3 Have a continuous quality improvement (CQI) strategy?

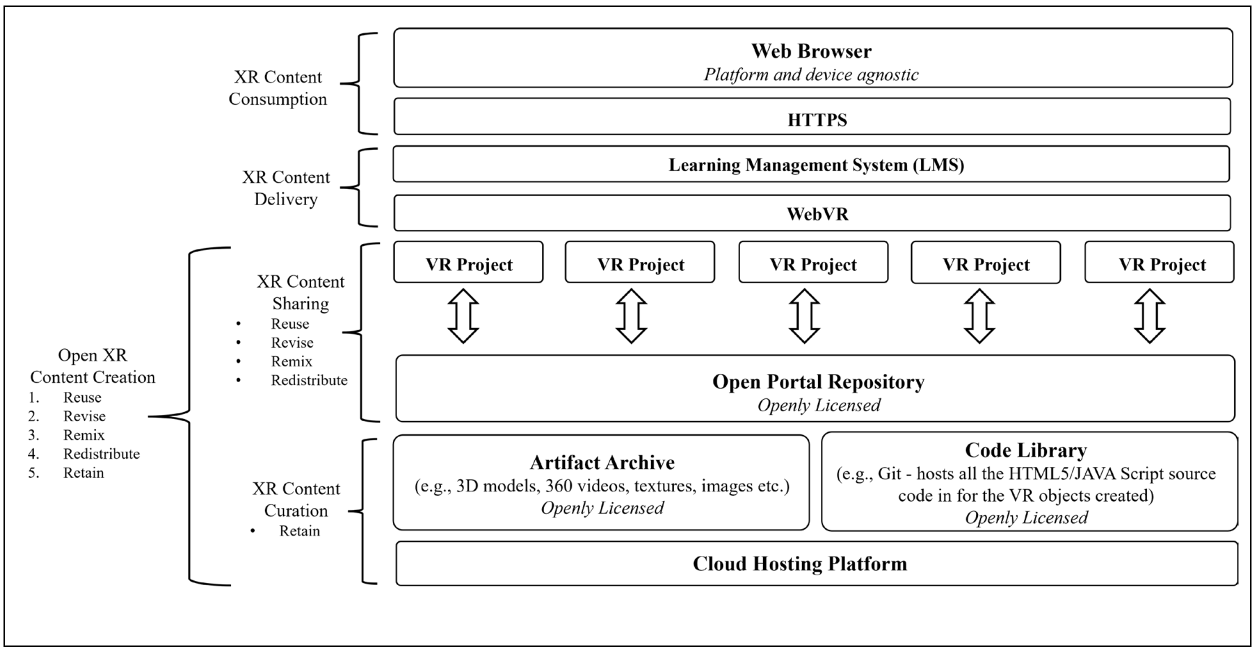
Note. Adapted from "An Empirical Framework for Mainstreaming OER in an Academic Institution" by I. S. Abeywardena, 2017, *Asian Association of Open Universities Journal, 12*(2), p. 233 (https://doi.org/10.1108/AAOUJ-11-2017-0036). CC BY 4.0.

Technology Infrastructure

When considering technology, both scalability and sustainability of educational technology projects heavily depend on (a) establishing productive partnerships among stakeholders, (b) identifying research-informed approaches to technology integration that are sustainable and scalable, and (c) developing sustainable and scalable approaches to technology integration (Niederhauser et al., 2018). XR content, including the artifacts, software code, and scripts among others, should be hosted and served using a FOSS architecture that adheres to OEP and open licensing. This enables the XR content to be reused, revised, remixed, redistributed, and retained for multiple projects within the same institution as well as collaborative projects across multiple institutions. Figure 4 identifies a technology infrastructure architecture which will be used for open XR content hosting, content reuse, content delivery and content consumption in the OXREF.

Figure 4

Technology Infrastructure Architecture for OXREF



Content Curation

Cloud Hosting Platform. Opting for managed cloud hosting infrastructure rather than setting up and maintaining on-premises hosting infrastructure is the prudent choice when considering medium to longer term scalability and sustainability of the XR initiative. Among the many benefits of cloud infrastructure, Dash and Pani (2016) highlighted (a) reduced costs, (b) promoting economic development, (c) enhanced transparency and accountability, (d) improved service delivery, (e) improved public administration, and (f) facilitating an e-society.

Artifact Archive. The artifact archive is an indexed and searchable storage space within the cloud infrastructure in which to curate all the artifacts, including script, 3D models, 2D graphics, video elements, and audio. Each element is tagged using an open metadata schema (Garnett et al., 2017; Taibi & Dietze, 2016) and is released under an open license.

For the Voyager VR example, the artifact archive consisted of the following.

- Script:
- Who? Spaceship, base station, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and docking station.
- Where? Outer space.
- What? Various shapes, colors, and sizes of the planets in our solar system.
- When? (a) Scene 1: spaceship leaving the base; (b) Scene 2: spaceship entering the solar system; (c) spaceship flying through the solar system; and (d) spaceship docking at the space station.
- 3D Models—spaceship, base station, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and docking station.
- 2D graphics—textures for the planet surfaces, planet names, and background space.
- Audio—spaceship engine noise and voiceover narrations.

Code Library. The code library is a distributed version control system commonly used in the software development industry to manage source code changes and version histories. It allows multiple programmers to work on a single project without compromising the integrity of the source code. Further, these systems are used widely for curating and archiving source code for reuse, revision, remixing, redistribution, and retention. A popular FOSS solution is Git (Spinellis, 2012), which can be set up on the cloud infrastructure, with an attached open license, allowing the reuse of source code.

From the Voyager VR example, the HTML and JavaScript source code used to animate the rocking motion of the spaceship, exhaust coming out of the spaceship engines, spaceship flying forward in space, and flashing lights at docking station will be stored in the code library.

Content Sharing

Open Portal Repository. The openly searchable repository is a portal repository (Beça et al., 2020) which allows stakeholders to search for artifacts and source code using a metadata or semantic search (Abeywardena & Chan, 2013). Once the user has located the artifacts and source code that are the best fit-for-purpose, they can download and reuse, revise, remix, redistribute, and retain depending on their teaching and learning needs. Further, depending on the open licenses used in the artifact archive and code library, the derivations will need to be shared alike back into the repositories, thereby promoting organic and sustainable growth. This, in turn, addresses the current lack of XR material for reuse, which is a major barrier to XR propagation in education (Murray & Johnson, 2021).

VR Projects. By remixing artifacts and code found through the open repository using open tools and platforms identified in Layer 1 and Layer 2 of the OXREF, users are able to rapidly develop derivative open XR objects fit-for-purpose for their teaching and learning needs.

The following is a new derivation of the Voyager VR example:

- Story (new)—provide learners a glimpse into the giant storms on the surface of the planet Jupiter.
- Script (revised):
- Who? Spaceship, base station, Jupiter, and docking station.
- Where? Outer space.
- What? A glimpse into the giant storms on the surface of the plane Jupiter.
- When? (a) Scene 1: spaceship leaving the base; (b) Scene 2: spaceship entering the solar system; (c) spaceship circling Jupiter; (d) spaceship flying close to the great red spot; and (d) spaceship docking at the space station.
- 3D models—spaceship, base station, Jupiter, and docking station.
- 2D graphics—textures for the planet Jupiter surfaces, planet names, and background space.
- Audio—spaceship engine noise and voiceover narrations (new).
- Animations—rocking motion of the spaceship, exhaust coming out of the spaceship engines, spaceship flying forward in space, flashing lights at docking station, spaceship circling Jupiter (new), and spaceship flying close to the great red spot (new).

Content Delivery and Consumption

WebVR is a non-immersive specification (Höhl, 2020) which allows XR content to be consumed using a Web browser (e.g., Microsoft Edge, Google Chrome, Mozilla Firefox, iOS Safari) without the use of specialist hardware or software such as VR headsets, Google Cardboard, or VR controllers. Due to the platform and device agnostic nature of WebVR, the user can interact directly with the XR content on the Web browser through a computer, keyboard-mouse or via a mobile device. With the current penetration rates of mobile devices and mobile Internet across the globe (Afzal et al., 2022), WebVR remains the most equitable and affordable method of consuming XR content. Further, as Dibbern et al. (2018) stated, “the best way to drive content creation is to get more creators invested. Integrating VR into the web gives us the opportunity to tap into the vast pool of web developers to design VR content” (p. 378). The studies by Rocha Estrada et al. (2022) and Glasserman-Morales et al. (2022) on virtual campuses claimed high satisfaction by teachers and learners when using WebVR, leading to increased uptake.

Among the key features of WebVR are its ability to (a) be served to end users through HTTPS; (b) be easily embedded in the learning management system (LMS), content management system (CMS), or webpage;

(c) be developed faster and cheaper using open tools and platforms; (d) avoid the need for additional apps or software downloads; and (e) facilitate quick and agile updates to the XR content which are instantly reflected to the end users; and (f) accommodate a do-it-yourself approach, thus empowering instructors to create more content themselves.

Operationalization Strategy

Ensuring XR initiatives are scalable and sustainable beyond the pilot phase requires a collaborative effort among many stakeholders. Ziker et al. (2021) stated that "optimizing the use of XR in higher education requires the support and resources of an interdisciplinary community of committed professionals from education, government, and industry who will work together with researchers to overcome the existing challenges that limit adoption" (p. 74). The OXREF looks at operationalization at the educational institution and the government levels.

Educational Institutional Level

Based on the work by Abeywardena (2012) and Abeywardena et al. (2019), Figure 5 outlines a four-stage operationalization strategy for the OXREF in an educational institution. Stages 1 to 3 have been discussed in detail in the preceding sections. Stage 4 addresses the need for institutional policy governing the use of XR in teaching and learning from several perspectives.

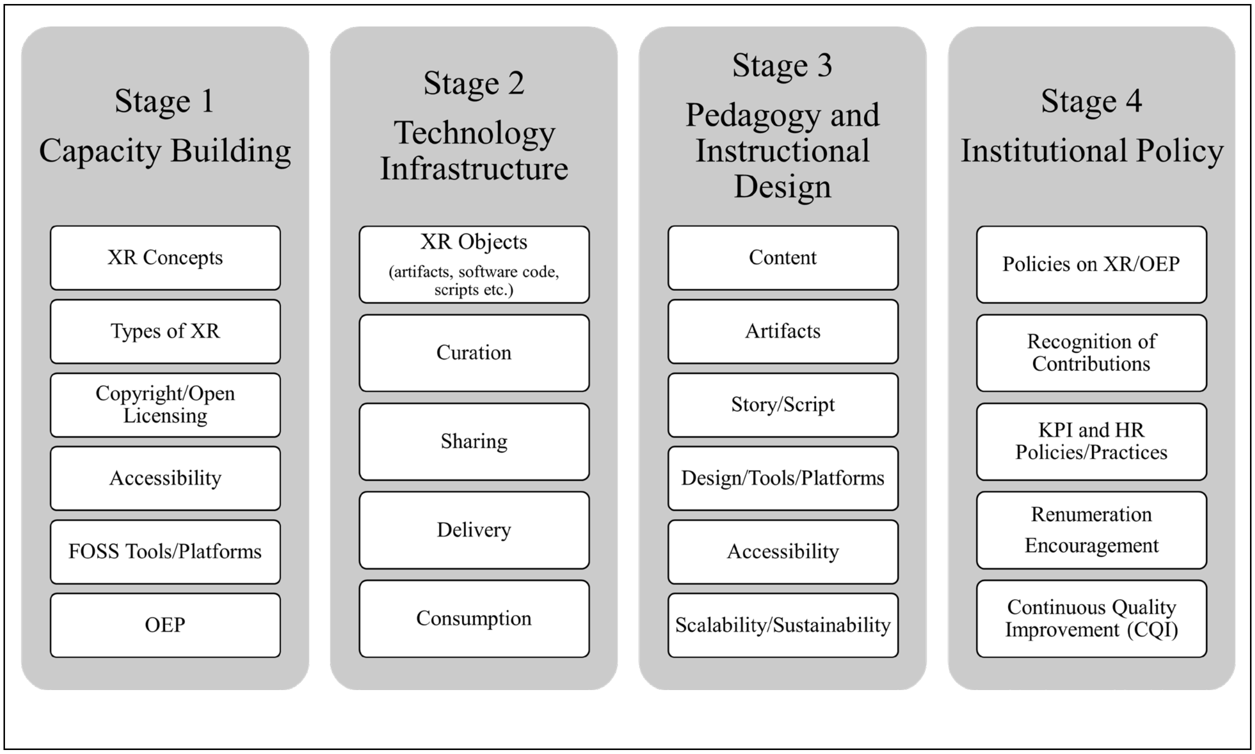
First, the institution needs to create policies, procedures, and guidelines around the use of XR in teaching and learning with respect to (a) the type of XR to be used—fully immersive, partially immersive, and/or non-immersive; (b) the type of open license to be used—use only one license across the institution or allow content creators to assign the license; and (c) the extent to which the institution will encourage OEP.

Second, the institution should revise their criteria for performance evaluation in order to consider impactful contributions made to teaching and learning through integrating XR into the curriculum. This could result in some form of recognition or renumeration which will encourage more uptake of XR within the institution.

Third, the institution should invest in formal processes for continuous quality improvement (CQI). Hogg and Hogg (1995) defined CQI in higher education as "teaching people in an organization to view themselves as part of a larger systematic operation" (p. 37). They also recommended "continually serving customers better and more economically, using the scientific method and teamwork, and focusing on removal of all forms of waste" (p. 1). CQI implies that the use of XR in teaching and learning requires periodic and consistent evaluation by soliciting feedback from all stakeholders and evaluating whether the XR is contributing to the expected competencies and/or learning outcomes.

Figure 5

OXREF Operationalization Strategy for Educational Institutions



Note. Adapted from "A Report on the Re-use and Adaptation of Open Educational Resources (OER): An Exploration of Technologies Available" by I.S. Abeywardena, 2012, Commonwealth of Learning, p. 52 (http://hdl.handle.net/11599/233). CC BY-SA 4.0.

Government Level

In an EDUCAUSE report, Pomerantz and Rode (2020) identified some of the major barriers hindering the wider adoption of XR including (a) the need for more educational XR apps, (b) not having students as innovation drivers, (c) rapid pace of change, (d) lack of collaboration, (e) limited external partnerships, (f) lack of community building, and (g) looking beyond the pandemic. Based on design thinking principles of experiment, create, and prototype models, then gather feedback and redesign (Razzouk & Shute, 2012). Table 2 provides a usable operationalization plan for governments to address the key issues of XR addressed through the OXREF.

Table 2

OXREF Operationalization Strategy for Governments

XR areas of need	Government support			
	Understand the case for XR	Design potential XR solutions	Build XR prototypes, test, refine	Implement XR solutions
Content, tools, and skills	Organize capacity building and skills development workshops on XR use in education.	Provide expert consultations; help identify industry partners and/or vendors.	Provide technical support and/or initial funding for specific technologies/ tools to instructors and learners using the XR technologies.	Provide consultation, user training, technical support, and/or funding for licenses aimed at large scale deployment.
Pedagogy and instructional design	Offer tailored suggestions on how to integrate XR into a particular curriculum.	Deliver training and support for instructors to use the technology.	Organize capacity building and skills development workshops for instructors and instructional designers on the integration of XR competencies/ learning outcomes.	Organize capacity building workshops on assessment of competencies/ learning outcomes in XR integrated courses.
Technology infrastructure	Act as the intermediary and/or liaison between partner institutions and industry partners/ vendors to provide access to XR technologies and platforms.	Negotiate and/or collaborate with industry partners/vendors on behalf of partner institutions to secure access to XR technologies and platform sandboxes.	Give education and training providers access to XR platforms and shared applications and content.	Give stakeholders access to XR technology (e.g., VR headsets, high-end computers), applications and content.
Scalability and sustainability	Conduct province, institution, community, industry, and	Assist institutions in developing roadmaps, policies, and procedures for	Negotiate longer term scalability and sustainability goals with	Make content available to constituents through public infrastructure.

	sector specific studies on areas of need in XR.	mainstreaming XR use.	industry partners/vendor.

Conclusion

The OXREF facilitates the creation of XR experiences for education in a scalable and sustainable manner using OER, OEP, FOSS, and open licensing. Further, the empirical framework outlined here promoted collaboration in XR reuse, revision, remixing, redistribution, and retention—both within the institution and across institutions—anchored by a robust technology infrastructure architecture. For example, if one institution develops an XR simulation of the human heart, another a human brain, and another a human lung using the OXREF, all of them and many others will be able to combine multiples of these simulations, under open licenses, to create robust XR simulations of the human anatomy. Such simulations would support the competencies or learning outcomes of an entire course or program. Further, the share alike conditions of using open XR content would contribute to organic growth of the XR content available for reuse. Acknowledging the importance of pedagogy and instructional design in integrating XR into curricula, the OXREF provides a set of instructional design factors to be considered in XR simulations. Further, it includes an XR operationalization readiness checklist along with strategies for educational institutions and governments. I am working towards the implementation of the OXREF at the University of Waterloo in the future.

Acknowledgements

The initial draft version of the OXREF was first presented at the Innovations in Education Conference(2021), Ontario, Canada.

I acknowledge the support provided by Aldo Caputo, Director of the Centre for Extended Learning, University of Waterloo.

References

Abeywardena, I. S. (2012). *A report on the re-use and adaptation of open educational resources (OER): An exploration of technologies available*. Commonwealth of Learning. http://hdl.handle.net/11599/233

Abeywardena, I. S. (2017). An empirical framework for mainstreaming OER in an academic institution. *Asian Association of Open Universities Journal, 12*(2), 230–242. https://doi.org/10.1108/AAOUJ-11-2017-0036

Abeywardena, I. S. (2021, December). *Open extended reality for education framework (OXREF): Mainstreaming XR through institutional collaboration* [Conference session]. Waterloo Information Technology and Information Systems (WatITis) Conference. https://www.researchgate.net/publication/356878877_OXREF_Open_Extended_Reality_for_Education_Framework

Abeywardena, I. S., & Chan, C. S. (2013). Review of the current OER search dilemma [Conference session]. *Proceedings of the 57th World Assembly of International Council on Education for Teaching,* (ICET 2013, pp. 25–28). Nonthaburi, Thailand. https://www.researchgate.net/profile/Ishan-Abeywardena/publication/240310607_Review_of_the_Current_OER_Search_Dilemma/links/02e7e51c54e3671bc4000000/Review-of-the-Current-OER-Search-Dilemma.pdf

Abeywardena, I. S., Raviraja, S., & Tham, C. Y. (2012). Conceptual framework for parametrically measuring the desirability of open educational resources using D-index. *International Review of Research in Open and Distributed Learning, 13*(2), 59–76. https://doi.org/10.19173/irrodl.v13i2.1177

Abeywardena, I. S., Uys, P. M., & Fifita, S. (2019). OER mainstreaming in Tonga. *International Review of Research in Open and Distributed Learning, 20*(1). https://doi.org/10.19173/irrodl.v20i1.3924

Afzal, A., Firdousi, S. F., Waqar, A., & Awais, M. (2022). The influence of Internet penetration on poverty and income inequality. *SAGE Open, 12*(3), 1–17. https://doi.org/10.1177/21582440221116104

Alizadehsalehi, S., Hadavi, A., & Huang, J. C. (2020). From BIM to extended reality in AEC industry. *Automation in Construction, 116*, 103254. https://doi.org/10.1016/j.autcon.2020.103254

Beça, P., Ribeiro, S., Santos, R., Aresta, M., Veloso, A. I., & Ortet, C. (2020). Design and initial evaluation of an online portal-repository: The case of Gamers4Nature project. In N. Martins & D. Brandão, (Eds.), *Proceedings of Advances in Design and Digital Communication* (Digicom 2020). Springer Series in Design and Innovation (Vol. 12, pp. 137–147). Springer. https://doi.org/10.1007/978-3-030-61671-7_13

Cronin, C. (2017). Openness and praxis: Exploring the use of open educational practices in higher education. *International Review of Research in Open and Distributed Learning, 18*(5), 15–34. https://doi.org/10.19173/irrodl.v18i5.3096

Dash, S., & Pani, S. K. (2016). E-Governance paradigm using cloud infrastructure: Benefits and challenges. *Procedia Computer Science, 85,* 843–855. https://doi.org/10.1016/j.procs.2016.05.274

Dibbern, C., Uhr, M., Krupke, D., & Steinicke, F. (2018). Can WebVR further the adoption of virtual reality? In S. Hess & H. Fischer (Eds.), *Humans and Computers 2018: Usability Professionals*, (pp. 377–384). https://doi.org/10.18420/muc2018-up-0249

Doolani, S., Wessels, C., Kanal, V., Sevastopoulos, C., Jaiswal, A., Nambiappan, H., & Makedon, F. (2020). A review of extended reality (xr) technologies for manufacturing training. *Technologies, 8*(4), 77–97. https://doi.org/10.3390/technologies8040077

EDUCAUSE. (2018, May). *eXtended reality (XR): How AR, VR, and MR are extending learning opportunities*. https://events.educause.edu/eli/focus-sessions/2018/extended-reality-xr-how-ar-vr-and-mr-are-extending-learning-opportunities

Fernandez, M. (2017). Augmented virtual reality: How to improve education systems. *Higher Learning Research Communications, 7*(1), 1–15. https://doi.org/10.18870/hlrc.v7i1.373

Friesen, N. (2009). Open educational resources: New possibilities for change and sustainability. *International Review of Research in Open and Distributed Learning, 10*(5). https://doi.org/10.19173/irrodl.v10i5.664

Garcia Estrada, J., & Prasolova-Førland, E. (2022). Running an XR lab in the context of COVID-19 pandemic: Lessons learned from a Norwegian university. *Education and Information Technologies, 27*(1), 773–789. https://doi.org/10.1007/s10639-021-10446-x

Garnett, A., Leahey, A., Savard, D., Towell, B., & Wilson, L. (2017). Open metadata for research data discovery in Canada. *Journal of Library Metadata, 17*(3–4), 201–217. https://doi.org/10.1080/19386389.2018.1443698

Glasserman-Morales, L. D., Ruiz-Ramírez, J. A., & Estrada, F. J. (2022). Transforming higher education using WebVR: A case study. *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, 17*(3), 230–234. https://doi.org/10.1109/RITA.2022.3191257

Guilbaud, P., Guilbaud, T. C., & Jennings, D. (2021). Extended reality, pedagogy, and career readiness: A review of literature. *Virtual, Augmented and Mixed Reality: Proceedings of the International Conference on Human-Computer Interaction* (pp. 595–613). Springer. https://doi.org/10.1007/978-3-030-77599-5_41

Hogg, R., & Hogg, M. (1995). Continuous quality improvement in higher education. *International Statistical Review, 63*(1), 35–48. https://doi.org/10.2307/1403776

Höhl, W. (2020). Official survey data and virtual worlds: Designing an integrative and economical open source production pipeline for XR-applications in small and medium-sized enterprises. *Big Data and Cognitive Computing, 4*(4), 26. https://doi.org/10.3390/bdcc4040026

India Blooms News Service. (2017, December 16). *Samsung India partners with UNESCO to launch VR content and 360-degree videos*. https://www.indiablooms.com/finance-details/8251/samsung-india-partners-with-unesco-to-launch-vr-content-and-360-degree-videos.html

Khan, T., Johnston, K., & Ophoff, J. (2019). The impact of an augmented reality application on learning motivation of students. *Advances in Human-Computer Interaction, 2019*, 1–14. https://doi.org/10.1155/2019/7208494

Kluge, M. G., Maltby, S., Keynes, A., Nalivaiko, E., Evans, D. J., & Walker, F. R. (2022). Current state and general perceptions of the use of extended reality (XR) technology at the University of Newcastle: Interviews and surveys from staff and students. *SAGE Open, 12*(2). https://doi.org/10.1177/21582440221093348

Koseoglu, S., & Bozkurt, A. (2018). An exploratory literature review on open educational practices. *Distance Education, 39*(4), 441–461. https://doi.org/10.1080/01587919.2018.1520042

Lai, J. W., & Cheong, K. H. (2022). Adoption of virtual and augmented reality for mathematics education: A scoping review. *IEEE Access, 10*, 13693–13703. https://doi.org/10.1109/ACCESS.2022.3145991

MacKinnon, T., Pasfield-Neofitou, S., Manns, H., & Grant, S. (2016). A meta-analysis of open educational communities of practice and sustainability in higher educational policy. *Apprentissage des Langues et Systèmes d'Information et de Communication, 19*(1). https://doi.org/10.4000/alsic.2908

McGreal, R. (2017). Special report on the role of open educational resources in supporting the sustainable development goal 4: Quality education challenges and opportunities. *The International Review of Research in Open and Distributed Learning, 18*(7). https://doi.org/10.19173/irrodl.v18i7.3541

Meccawy, M. (2022). Creating an immersive XR learning experience: A roadmap for educators. *Electronics, 11*(21), 3547. https://doi.org/10.3390/electronics11213547

Mourchid, Y., Renoust, B., Cherifi, H., & El Hassouni, M. (2018). Multilayer network model of movie script. In L. Aiello, C. Cherifi, H. Cherifi, R. Lambiotte, P. Lió & L. Rocha (Eds.), *Complex Networks and Their Applications* (Vol. 812, pp. 782–796). Springer. https://doi.org/10.1007/978-3-030-05411-3_62

Murray, J. T., & Johnson, E. K. (2021). XR content authoring challenges: The creator-developer divide. In J. A. Fisher (Ed.), *Augmented and Mixed Reality for Communities* (pp. 245–264). CRC Press. https://doi.org/10.1201/9781003052838

Niederhauser, D. S., Howard, S. K., Voogt, J., Agyei, D. D., Laferriere, T., Tondeur, J., & Cox, M. J. (2018). Sustainability and scalability in educational technology initiatives: Research-informed practice. *Technology, Knowledge and Learning, 23*(3), 507–523. https://doi.org/10.1007/s10758-018-9382-z

Pomerantz, J., & Rode, R. (2020). *Exploring the future of extended reality in higher education*. EDUCAUSE. https://er.educause.edu/articles/2020/6/exploring-the-future-of-extended-reality-in-higher-education

Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research, 82*(3), 330–348. https://doi.org/10.3102/0034654312457429

Renz, A., & Hilbig, R. (2020). Prerequisites for artificial intelligence in further education: Identification of drivers, barriers, and business models of educational technology companies. *International Journal of Educational Technology in Higher Education, 17*(1), 1–21. https://doi.org/10.1186/s41239-020-00193-3

Rocha Estrada, F. J., Ruiz-Ramírez, J. A., George-Reyes, C. E., & Glasserman-Morales, L. (2022). Evaluation of a virtual campus adapted to WebVR spaces: Assessments of teachers and students. *Frontiers in Education, 7*, 396. https://doi.org/10.3389/feduc.2022.918125

Rokhsaritalemi, S., Sadeghi-Niaraki, A., & Choi, S. M. (2020). A review on mixed reality: Current trends, challenges and prospects. *Applied Sciences, 10*(2), 636–662. https://doi.org/10.3390/app10020636

Schwaiger, M. (2021). Europe needs to integrate immersive learning quickly at all education levels—But how? What to learn from 25 EU projects in this field. *Journal of Elementary Education, 14*(Special Issue), 63–85. https://doi.org/10.18690/rei.14.Spec.Iss.63-85.2021

Simon-Liedtke, J. T., Baraas, R., & Regnesentral, N. (2022). The future of extended reality in primary and secondary education. *Studies in Health Technology and Informatics, 297*, 549–556. https://doi.org/10.3233/SHTI220886

Spinellis, D. (2012). Git. *IEEE Software, 29*(3), 100–101. https://ieeexplore.ieee.org/document/6188603

Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of Communication, 42*(4), 73–93. https://doi.org/10.1111/j.1460-2466.1992.tb00812.x

Taibi, D., & Dietze, S. (2016). Towards embedded markup of learning resources on the web: An initial quantitative analysis of LRMI terms usage. In *Proceedings of the 25th International Conference Companion on World Wide Web* (pp. 513–517).

https://dl.acm.org/doi/pdf/10.1145/2872518.2890464?casa_token=VvysNQ6m2qMAAAAA:4uM2l6SBqIOVTXGfjKQkjRJ1lD5ew_GQYFb_5CyYXLFyyU3IFMP538QeLyof3bCF_TVjwxqXdNt6

The Shady Bunch. (2018, December 24). Voyager: Virtual reality (VR) journey through space [Video]. YouTube. https://youtu.be/Tn1TqYHPrUM

Tlili, A., Nascimbeni, F., Burgos, D., Zhang, X., Huang, R., & Chang, T. W. (2021). The evolution of sustainability models for open educational resources: Insights from the literature and experts. *Interactive Learning Environments*, *31*(3), 1–16. https://doi.org/10.1080/10494820.2020.1839507

United Nations Virtual Reality. (2017, June 17). *Refugee realities: Bringing individual refugee stories to the OECD*. Retrieved December 28, 2022 from http://unvr.sdgactioncampaign.org/2017/06/14/refugee-realities-bringing-individual-refugee-stories-to-the-oecd/#.ZGubKX3MK5c

Wang, M., Ryoo, J., & Winkelmann, K. (2020). Preface to the special issue on cross reality (XR) and immersive learning environments (ILE) in education. *Interactive Learning Environments, 28*(5), 539–542. https://doi.org/10.1080/10494820.2019.1696845

Yanckello, R. (2022, October 28). *Hype cycle for higher education, 2022* [Conference session]. EDUCAUSE Annual Conference 2022. https://events.educause.edu/annual-conference/2022/agenda/hype-cycle-for-higher-education-2022

Yang, K., Zhou, X., & Radu, I. (2020). *XR-ed framework: Designing instruction-driven and learner-centered extended reality systems for education*. ArXiv. https://doi.org/10.48550/arXiv.2010.13779

Ziker, C., Truman, B., & Dodds, H. (2021). Cross reality (XR): Challenges and opportunities across the spectrum. In J. Ryoo & K. Winkelmann (Eds.), *Innovative learning environments in STEM higher education: Opportunities, challenges, and looking forward* (pp. 55–78). Springer Briefs in Statistics. https://doi.org/10.1007/978-3-030-58948-6_4