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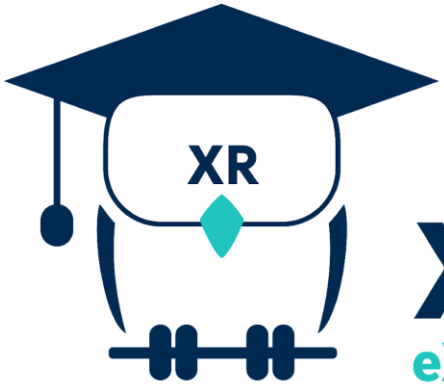

XR4ED
eXtended Reality for EDucation

D3.1
User/Technology requirement, existing tools and infrastructure - 1

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List of Acronyms

Acronym	Description
AR	Augmented Reality
DMA	Digital Markets Act
DoA	Description of Action
DOF	Degrees of Freedom
DSA	Digital Services Act
EdTech	Educational Technology
FEAT	Features
GDPR	General Data Protection Regulation
GM	Game Mechanics
LM	Learning Mechanics
MR	Mixed Reality
NONF	Non-Functional Requirements
NPC	Non-Player Character
PO	Project Coordinator
SMEs	Small and Medium-Sized Enterprises
TTS	Text-To-Speech
UC	Use Cases
VR	Virtual Reality
WP	Work Package
XR4ED	Extended Reality for Education

Changes for resubmission of the deliverable

In response to the feedback we received during the review process, we have made significant revisions to the 4.2 XR Educational and Learning Frameworks section of this deliverable. The feedback prompted a thorough reassessment of the section's content and so to address this, we conducted additional research in specific scientific databases like Scopus, Web of Science and Google Scholar to find literature reviews and analyses focusing on XR learning frameworks. Based on the comprehensive literature review conducted by Fernandes et al. (2023) which was suggested by the reviewer, we refined the section to highlight design decisions of the platform based on the frameworks. Additionally, we engaged in discussions with the technical partners to explore how these frameworks will be incorporated into the platform. Each framework was analysed in greater detail, and its use in the platform was meticulously outlined.

Executive Summary

The specific deliverable entitled “User/Technology requirement, existing tools and infrastructure - 1” outlines a user-centered design approach employed in the development of initial user requirements for the XR4ED project. The process involves the utilization of questionnaires to gather valuable insights regarding the user requirements for XR in education. Moreover, the deliverable investigates the adaptability of existing educational and learning frameworks for the Extended Reality (XR) authoring tool and platform. Additionally, this deliverable focuses on the draft formulation of functional and non-functional specifications for XR4ED services and applications. These specifications encompass system functions and component interactions that cater to the needs of the domain and users, and are presented in a comprehensive manner, including descriptions of involved actors and related elements. By applying user-centered design principles and leveraging the consortium's collective expertise, this research aims to ensure the development of an effective XR4ED solution. The next updated deliverable entitled “User/Technology requirement, existing tools and infrastructure - 2” with a deadline in a few months (month 8), will be submitted with more specific and validated use cases and the identification of the technical requirements of the XR4ED platform as well as of the components to be integrated, identifying their interfaces, data schemas and operational and functional requirements. Therefore, D3.4 will receive as input the report of D3.1, towards identifying the technical constraints and specifications of the platform to be designed.

I Introduction

The European EdTech sector is playing an increasingly important role in driving forward digital transformation in Europe covering all education and training sectors. According to estimates, the sector saw a 15% increase in investments in 2021 and global investments are expected to reach over $87 billion in the upcoming decade. Notwithstanding, the sector is heavily fragmented across the European Union with many small players and few companies playing a global role.

The European XR industry has evolved and maintained a leading role globally in software and content production. The use of XR can expand the range of activities through which students can gain hands-on experience, enabling them to go beyond abstract knowledge and supporting skills-based teaching and learning. Currently, developing XR applications for education requires specialised knowledge and strong XR development skills. The process takes a lot of effort, time, and money.

The XR4ED concept is to:

a) **bring together EdTech and XR community and resources**, overcoming fragmentation issues and encouraging the acceleration of innovation for personalised, innovative, efficient, and inclusive learning using XR;

b) **build a one-stop shop and open marketplace for XR applications for learning, training and education** that will act as a European reference platform on learning and teaching with XR4ED will focus on the following sectors which must be further developed to make Europe a leader in cutting-edge technologies for education:

- Boost the deployment of innovative XR applications for learning, training, and education.
- Enable digital start-ups, small and medium-sized enterprises (SMEs), and industry active in the EdTech sector to further advance early prototypes, of digital learning solutions/apps using XR to a market-ready product.
- Provide a single point of access to XR content, tools and solutions based on open standards.
- Provide links to existing relevant initiatives and projects, including existing platforms, catalogues, or repositories.

This is the first version of the document, while the final version (D3.4) will be submitted in month 8, according to the workplan. The purpose of this document is to outline the initial user requirements which are essential to meet the specific project objectives of the XR4ED project. This is included as part of WP3 for the XR4ED project and is specifically the deliverable of Task 3.1.

To understand the user requirements, XR4ED applied principles of user-centred design developed from several validated questionnaires. The objective was to design and distribute questionnaires to the

scientific community (universities, schools, research centers, XR developers and experts in partnership) and gather anonymous information regarding XR and education.

The purpose of this task was also to review existing educational and learning frameworks which can be adopted for our XR authoring tool and platform. Furthermore, the functional and non-functional specifications of the XR4ED services and applications were drafted. They will need to be validated however, in the next deliverable, D3.4 in month 8. The latter includes a set of system functions and component interactions that fulfil the domain and user needs.

Until now, we have received 60 questionnaires from **experts** and 19 from **students** (above 18 years of age). In the second phase (D3.4), the questionnaires are expected to reach more experts and students so that more concrete generalisations can be obtained. In addition, interviews will be conducted with members of the consortium and external experts. We estimate that they will provide valuable feedback to finalise and validate our use cases and thereby meet the requirements for the XR4ED project. The requirements outlined in this document will then correspondingly outline the user requirements for the XR authoring tool and the XR platform based on the needs of the targeted users.

2 User Requirements Capture and Analysis Methodology

2.1 Overview of Methodology

The user requirements and analysis methodology consist of essential parts of XR in education as they serve as the foundation for any successful collaboration or project. A clear understanding of the needs, expectations, and preferences of the users or stakeholders involved will lead to higher customer satisfaction and a greater likelihood of achieving the desired outcomes.

Users' requirements capture has two objectives:

(1) Find the "true" requirements and
(2) Represent the "true" requirements in a suitable way for the users, customers, and developers.

The term 'true requirements' refers to the implemented requirements that will add value to the users. The resulting description of the requirements must be understandable by users and customers.

To build a system that truly meets the customers' needs, it is essential to clearly define the problem. As a next step the stakeholders of the system are identified, along with their business and user requirements. These elicited businesses and user's requirements are checked and analysed to be comprehensively described and prioritized. Finally, a set of product and system features will be implemented according to these set of high-level expectations.

Detailed system requirements are then derived and used as input for the technical requirements and system design specifications as well as for test plans and procedures needed for implementation and validation. This straightforward approach is based on use cases. Normally, a system has many types of users. Each type of user is represented as an actor. Actors use the system as they interact with use cases. A use case is a sequence of actions that the system performs to offer some results of value to an actor. All the actors and the use cases of a system make up a use-case model. During analysis and design, the use-case model is transformed into a design model through an analysis model.

This deliverable takes first steps in identifying, analysing and evaluating the user needs. The follow up deliverable will finalise these steps, aiming at the successful instructional design, pedagogical effectiveness, and user satisfaction of XR technology.

2.2 Managing Requirements

Proper management of the XR4ED user requirements is crucial for organizations to ensure accurate capture, documentation, and addressing of user needs throughout the collaboration lifecycle. Managing requirements involves various key activities such as elicitation, analysis, documentation, prioritization, validation, verification, traceability, change management, and stakeholder engagement. The benefits of effective requirements management are numerous. It guarantees a customer-centric approach, aligns

collaborations with user expectations, establishes clear project scope, facilitates effective decision-making, risk mitigation, and resource allocation. Stakeholder engagement ensures that requirements are understood, validated, and updated as required. By applying a systematic approach to requirements management, organizations can enhance collaboration outcomes, maximize user satisfaction, and minimize scope creep. In conclusion, within the project, the effective management of user requirements will be a priority, ensuring that collaboration efforts align closely with user needs and expectations.

2.3 Identifying Requirement Types

A requirement type is simply a class of requirements. By identifying **types of requirements**, teams can organize large numbers of requirements into meaningful and more manageable groups. Establishing different types of requirements in a project assist team members to classify requests for changes and to communicate more clearly. Usually, one type of requirement can be broken down, into other types.

Use cases and other forms of modeling are used to derive design requirements that can be further disintegrated into software requirements. When there are many requirements in each project, classifying requirements into types makes the project more manageable. For the needs of the XR4ED project the following requirement types are necessary to be further investigated:

- Features – FEAT
- Use Cases – UC /Functional Requirements
- Non-Functional Requirements – NONF
    - Hardware and Software Requirements
    - User Interface Requirement
- Environmental Requirements
- Accessibility Requirements
- Compliance Requirements
- Documentation Requirements
- Assessment

2.4 Identifying Multi-Dimensional Attributes

When assessing potential partners for collaboration, it is essential to consider various attributes that extend beyond basic criteria. By considering these multi-dimensional attributes specific to each user type, organizations can ensure that their collaboration efforts address the diverse needs and expectations of different user groups, leading to enhanced user satisfaction and a more successful collaboration. However, to assess and manage project requirements, attributes such as status, priority, benefit, and risk are essential to be used. Requirements may be:

- assigned priorities,
- identified by source and rationale, delegated to specific sub-teams within a functional area, given a degree-of-difficulty designation,
- associated with a particular iteration of the system.

The requirement type and their attributes are defined for the entire project, ensuring usage consistency across the team.

By examining the attribute values, we can gather significant information about each requirement, even without showing the complete text for each one. For example, priority and importance – undoubtedly assigned by different members of the team – will help the team begin to scope the project to available resources and time, considering both the stakeholder priorities and a very rough estimate of effort reflected in the value of the difficulty attribute. Within the scope of XR4ED project, the following attributes were considered necessary for each of the requirement types mentioned above:

Attribute	Description and Possible Values
Status	Tracks progress during the definition of the project baseline and subsequent development. Set after negotiation and review by the partners. Possible values: • **Proposed**: used to describe features that are under discussion but have not yet been reviewed and accepted by concerned partners. • **Approved**: used to describe features that are deemed useful and feasible and have been approved by the partners. • **Not Approved**: used to describe features not to be incorporated in the system specification.
Priority/Benefit	Ranking by relative priority or benefit to the end user opens a dialogue between partners to decide to incorporate features proposed by any of the team members and/or users. Possible values: • **Critical**: features that exist in the Initial Requirements and are also important for the XR4ED overall functionality. All critical features must be implemented in the first release of the system, as they are high-priority requirements. • **Important**: features that exist in the Initial Requirements or are important for the XR4ED overall functionality. All-important features are strongly desired but could be implemented in the next release. • **Nice-to-have**: used for features that enhance the competitiveness of the product. Based on state-of-the-art customer service systems.

	They are low-priority requirements and so they are desired but optional.
Risk	Risk attribute refers to the negative impact or uncertainty related to a requirement. The risk attribute consists of mitigation strategies to minimize the potential effects of the project's success. Possible values: • **Severity**: the potential consequences of the risk occurring • **Likelihood**: the probability of the risk occurring • **Impact**: magnitude of the effect the risk poses on the project's outcomes.

Table 1: *Attributes assigned to XR4ED Features*

Attribute	Description and Possible Values
Priority/Benefit	Ranking by relative priority or benefit to the users opens a dialogue between XR4ED team to decide to incorporate functional requirements proposed by any of the users. Possible values: • **Critical**: functional requirements which are highly important for the XR4ED overall functionality. All critical non-functional requirements must be implemented in the first release. • **Important**: functional requirements that are important for the competitiveness of the product, based on design guidelines, legal guidelines, or state-of-the-art customer service systems. • **Nice to have**: used for functional requirements that enhance the competitiveness of the product. Nice to have requirements that are mainly based on market research. • **N/A**: used for use case steps that are initiated by actors.
Risk	Risk attribute refers to the negative impact or uncertainty related to a requirement. The risk attribute consists of mitigation strategies to minimize the potential effects of the project's success. • Severity: the potential consequences of the risk occurring • Likelihood: the probability of the risk occurring • Impact: magnitude of the effect the risk poses on the project's outcomes.

Table 2: *Attributes assigned to XR4ED Functional Requirements - Use Cases*

Attribute	Description and Possible Values
Status	Tracks progress during definition of the project baseline and subsequent development. Set after negotiation and review by the XR4ED team. Possible values: • **Proposed**: used to describe non-functional requirements that are under discussion but have not yet been reviewed and accepted by the team. • **Approved**: used to describe non-functional requirements that are deemed useful and feasible and have been approved by the team. • **Not Approved**: used to describe non-functional requirements to be incorporated in the system specification.
Priority/Benefit	Ranking by relative priority or benefit to the user opens a dialogue between the XR4ED team to decide to incorporate non-functional requirements proposed by any member of the team. Possible values: • **Critical**: non-functional requirements that are highly important for the XR4ED's overall functionality. All critical non-functional requirements must be implemented in the first release. • **Important**: non-functional requirements that are important for the competitiveness of the product, based on design guidelines, legal guidelines or state-of-the-art customer service systems. • **Nice to have**: used for non-functional requirements which enhance the competitiveness of the product. Nice to have requirements that are mainly based on market research.
Risk	Risk attribute refers to the negative impact or uncertainty related to a requirement. The risk attribute consists of mitigation strategies to minimize the potential effects of the project's success. • **Severity**: the potential consequences of the risk occurring • **Likelihood**: the probability of the risk occurring • **Impact**: magnitude of the effect the risk poses on the project's outcomes.

Table 3: *Attributes assigned to XR4ED Non-Functional Requirements*

- ***Environmental Requirements:*** The XR application should be designed to work in a variety of settings, including classrooms, laboratories, and remote learning environments. It should also be adaptable to different lighting conditions and other environmental factors.
- ***Accessibility Requirements:*** The XR application should be designed to be accessible to all learners, including those with disabilities, by incorporating features such as alternative input methods and adjustable font sizes. The content should be designed to cater to learners with disabilities, such as visual or auditory impairments.
- ***Compliance Requirements:*** The XR application should be designed to comply with all relevant regulations and standards, including those related to data privacy and security.
- ***Documentation Requirements:*** The XR application should be fully documented, with clear instructions for installation, setup, and use, as well as user guides and technical support resources.
- ***Hardware and software requirements:*** List the hardware and software requirements needed to run the XR application, such as specific devices, operating systems, and software versions.
- ***User Interface Requirements:*** The XR application should be designed to be intuitive and easy to use, with a user-friendly interface that enables users to navigate through different modules and interact with different objects and environments.
- ***Assessment:*** Assessment is an essential component of education. XR content should include assessment tools to measure the learning outcomes of the learners.

2.5 Identifying Traceability Relationships

As implied in the description of requirement types, no single expression of a requirement stands alone. User requests are related to product features that are assigned to fulfil them. Product features are related to individual requirements that specify the features in terms of functional and non-functional behavior. Test cases are related to the requirements they verify and validate. Requirements may be dependent on other requirements, or they may be mutually exclusive. For teams to determine the impact of changes and feel confident that the system conforms to expectations, these traceability relationships must be understood, documented, and maintained. While traceability is one of the most difficult concepts to implement in requirements management, it is essential to accommodate changes. Establishing clear requirement types and incorporating cross-functional participation can make traceability easier to implement and maintain. An illustration of requirements traceability as well as the establishment of traceability paths is shown in **Figure 1**.

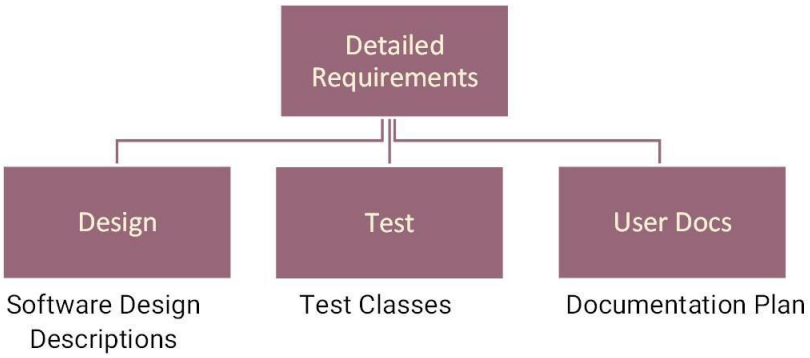

Figure 1: *Requirements Traceability - Establish Traceability Paths*

Within the scope of the XR4ED User Requirements report, the following traceability relationships seem to be necessary to be identified and recorded:

- Features to Use Cases
- Functional Requirement Specifications
- Features of Non-Functional Requirements
- Environmental Requirements
- Accessibility Requirements
- Compliance Requirements
- Documentation Requirements
- Hardware and Software Requirements
- User Interface Requirements
- Assessment

3 User Requirements Identification

To effectively provide products and services that meet the users' real needs, it is necessary to identify and involve all types of users as part of the Requirements Modeling process. The potential users of the system are identified, ensuring that the stakeholder community represents them adequately. This section provides a profile of the representative users involved in the project and the key problems that they perceive to be addressed by the proposed solution.

The user requirements document was developed based on literature review and 2 target groups. The target groups were – one with experts from the expert's community (universities, schools, research centers, XR developers and experts in partnership) and another one with students and young people (over 18 years old). The questionnaires included questions that were validated through empirical studies (see section 3.2). The questions for the experts can be found in **ANNEX I** and for the students in **ANNEX II**.

The questionnaires provided a basis to further detail the use cases and therefore the initial requirements for the XR4ED project. The questionnaires were distributed in Google forms via email and they were anonymous.

3.1 Overview of Users

The end-user profile for XR applications for education is diverse and includes various groups. Each group accesses the tool in different ways based on their specific needs and interests:

- **XR Developers**: This target group consists of developers who are interested in creating educational XR applications. They access the tool to leverage its features and resources for designing and implementing XR experiences in the field of education. They utilize the development tools, frameworks, and documentation provided by the system to create engaging and interactive XR applications tailored for educational purposes.
- **Business Community**: The business community, including SMEs (small and medium enterprises) and companies operating at the national or European level in XR platforms, repositories, libraries, instructional design, system integration, investments, and hardware providers, utilizes the tool to explore opportunities in the educational XR market. They access the system to access XR content repositories, integrate XR technology into their existing platforms or services, invest in XR-based educational solutions, and provide hardware support for XR implementation in educational settings.
- **Scientific Community**: The scientific community, comprising universities, research centers, and schools, particularly those specializing in STEM (Science, Technology, Engineering, and Mathematics), history, healthcare, and related fields, benefits from the tool to enhance their educational practices. They utilize the system's XR resources, educational materials, and learning modules to create immersive and interactive learning experiences for their students. Additionally,

researchers and educators within this group may contribute to the development of XR applications and collaborate with other stakeholders.

- **Young Professionals**: Young professionals seeking training and upskilling in industries such as healthcare, medical, manufacturing, construction, and engineering utilize the tool to access XR-based training programs. They can undergo virtual simulations, practical exercises, and hands-on experiences through XR applications provided by the system. This group benefits from immersive learning opportunities that help them acquire practical skills and knowledge in their respective fields.
- **Social Innovators**: Social innovators involved in ethics and policy regulation for XR applications in education at the national or state level utilize the tool to stay informed and contribute to the development of ethical guidelines and policy frameworks. They access the system to gather insights, review XR applications' educational impact, and provide recommendations for responsible and effective use of XR technology in educational settings.

Therefore, the XR tool serves a diverse range of end-users including XR developers, the business community, the scientific community, young professionals, and social innovators. Each group accesses the tool in distinct ways, leveraging its features and resources to create, integrate, enhance, train, and regulate XR applications for educational purposes.

3.2 Questionnaires

3.2.1 Methodology

The objective of the questionnaire to be used for the requirements-capturing process is to define the day-to-day requirements that users will have from the XR4ED system.

Prior to building a questionnaire that fully captures the customers' needs, it is deemed essential to answer some basic questions regarding the eventual usage of the system, namely, who will be the eventual users of the system, hence who should be responding to this questionnaire, and what are the processes and general features we want to examine.

The integrated questionnaires can be found in **ANNEX I** and **ANNEX II**. The integrated questionnaires were constructed from 5 validated questionnaires 1, 2, 3, 4, 5]. In this way, we did not have to validate the questions. One questionnaire was designed for students (over 18 years old), and one targeted expert coming from the scientific and business community (universities, colleges, schools, research centers, XR developers and experts in the partnership).

3.2.2 Structure

The structure of the integrated questionnaires concerning the end users (both students and experts) is organized as follows:

Questionnaire for Experts

- The first section concerns characteristics of the End user's business, age and experience outlining the profile of the participant.
- The second section refers to the exposure of the participants to XR technologies prior to their use as a teaching tool. The questions in this section will provide feedback to us regarding the devices the End users currently use. It also aims to obtain a view of the market.
- The third section attempts to capture the opinion of the participants regarding the XR technology tool – metrics while seeking to gauge the respondent's usage and familiarity with XR (AR, VR, MR) technologies. Respondents are asked to rate the difficulty of navigating these technologies with a head-mounted display and joystick. The survey also includes questions that aim to understand the respondents' experience with alternative technologies as a teaching tool and the level of inconvenience associated with costs, spatial limitations, demand for technical and human resources, the requirement of specific knowledge by teachers and technicians, and technological obsolescence.
- The fourth section attempts to capture the opinion of the participants regarding their willingness to develop and use XR technology as a teaching tool. (Applied only to the scientific community and experts from the partnership etc.)
- The fifth section concerns the General Attitude towards XR technologies in educational settings.

Questionnaire for Students (above 18-year-old)

- The first section concerns characteristics of the End user's business, age and experience outlining the profile of the participant.
- The second section refers to the exposure of the participants to XR technologies prior to their use as a teaching tool. The questions in this section will provide feedback to us regarding the devices the end users currently use. It also aims to obtain a view of the market.
- The third section attempts to capture the opinion of the participants regarding the XR technology tool – metrics while seeking to gauge the respondent's usage and familiarity with XR (AR, VR, MR) technologies. Respondents are asked to rate the difficulty of navigating these technologies with a head-mounted display and joystick. The survey also includes questions that aim to understand the respondents' experience with alternative technologies as a teaching tool and the level of inconvenience associated with costs, spatial limitations, demand for technical and human resources, the requirement of specific knowledge by teachers and technicians, and technological obsolescence.
- The fourth section concerns the General Attitude towards XR technologies in educational settings.

3.2.3 Interviews

The interviews will take place in the upcoming months. They will follow a semi-structured approach using an open-ended question script querying views and experiences to gather valuable insights from the interviewees. Partners who are implementing a demonstration in the project will be interviewed to derive the use cases for the XR development features of the XR4ED platform. Experts will be also encouraged to complete the online survey, as described above. Ethical considerations will also be considered during the interview process, respecting the participants' privacy, and handling any sensitive data in accordance with applicable regulations.

4 Educational & Learning Frameworks for XR4ED Authoring Tool

4.1 Learning Theories

XR4ED will provide the necessary mechanisms and design processes for the design and integration of learning experiences based on a variety of theories and approaches to learning and instruction. In this scope, the following educational and learning theories & approaches that can be adopted by XR authoring tools will play a key role in informing the design of the XR4ED authoring tool.

- **Constructivist Learning Theory**: Constructivist learning theory emphasizes the role of the learner in constructing their own understanding of the world through active engagement with their environment. XR authoring tools can adopt this framework to help educators design XR learning experiences that encourage learners to explore, experiment, and construct their own knowledge and understanding [6].
- **Experiential Learning**: Experiential learning is a framework for learning that emphasizes the importance of hands-on, practical experience in the learning process. XR authoring tools can adopt this framework to help educators design XR learning experiences that enable learners to engage in immersive and interactive experiences that simulate real-world scenarios and problems [7].
- **Multiple Intelligences**: Multiple Intelligences theory suggests that individuals possess multiple types of intelligence, such as linguistic, logical-mathematical, musical, bodily-kinesthetic, spatial, interpersonal, and intrapersonal. This theory emphasizes the importance of recognizing and nurturing these different intelligences to support diverse learners [8].

4.2 XR Educational and Learning Frameworks

Educational and learning frameworks & design processes that can be adopted in the XR4ED platform:

1. **Successive Approximation Model (SAM):**

The Successive Approximation Model (SAM) presents an iterative design approach to designing and implementing learning experiences. SAM is based on rapid and iterative development of learning outcomes, encouraging collaborative configurations, while applying a creative problem-solving approach that aims at aligning stakeholders, helping them identify design challenges and proposing relevant solutions [9].

- *Detailed Implementation:*
  - The platform will feature a collaborative workspace where stakeholders can engage in rapid prototyping and iterative development (the marketplace).
  - SAM principles will be integrated into the XR content creation process, guiding users through successive approximations and refinements.
  - Educators and developers will have access to a dynamic feedback loop, fostering continuous improvement during the design and implementation phases.

2. **ADDIE Model:**

It is an instructional design model that presents both waterfall and iterative configurations that represents a systematic approach to creating instructional materials and learning experiences. ADDIE stands for Analysis, Design, Development, Implementation, and Evaluation [10].

- *Detailed Implementation:*
  - A dedicated dashboard within the platform will guide software developers through the distinct stages of Analysis, Design, Development, Implementation, and Evaluation.
  - Each stage will have associated tools and prompts, ensuring a systematic and thorough approach to XR content creation.
  - The platform will allow for revisiting and revising content based on the evaluation phase, promoting ongoing enhancement.

3. Bloom's Taxonomy:

Bloom's Taxonomy is a well-established framework for categorising educational objectives based on cognitive complexity (Figure 2 and Figure 3). It can be adopted by XR-authoring tools to help educators design XR learning experiences that engage learners at different levels of cognitive development, from basic knowledge acquisition to more complex critical thinking and problem-solving [11].

- *Detailed Implementation:*
  - XR-authoring tools will provide templates and guidance aligned with Bloom's Taxonomy, mapping different cognitive levels for learners.
  - Educators will have access to a content library categorised filtered according to Bloom's levels, aiding in the selection of appropriate XR activities.
  - The platform will include analytics tools to assess the alignment of the created content with targeted cognitive objectives.

4. SAMR Model:

The SAMR (Substitution, Augmentation, Modification, Redefinition) model is a framework for integrating technology into teaching and learning. XR authoring tools can adopt this model to help educators understand how XR technologies can be used to enhance and transform traditional teaching methods, rather than simply replacing them [12].

- *Detailed Implementation:*
  - Tutorials and resources within the platform will explain the SAMR model and its application in XR education.
  - XR-authoring tools will showcase how to substitute, augment, modify and redefine traditional teaching methods using XR technologies.
  - Use-case scenarios will illustrate transformative practices, inspiring educators to innovate within their teaching contexts.

5. Universal Design for Learning (UDL):

UDL is a framework for designing learning experiences that are accessible to all learners, regardless of their backgrounds or abilities. XR authoring tools can adopt this framework to help software developers create XR learning experiences that are designed to be inclusive and accessible to all learners, regardless of their individual learning needs [13].

- *Detailed Implementation:*
    - Accessibility features will be embedded in the platform, allowing software developers to design XR experiences catering to diverse learners.
    - Standardised guidelines will guide the developers in implementing UDL principles effectively.
    - The platform will offer customisable elements, ensuring adaptability to various learning styles and needs.

6. ARCS Model:

The ARCS (Attention, Relevance, Confidence, Satisfaction) Model is a framework for designing effective learning experiences. It helps ensure that learners are engaged and motivated to learn. The ARCS Model can be used to ensure that XR experiences are designed to capture the learners' attention and maintain their motivation [14].

- *Detailed Implementation:*
    - The platform will have prompts and design suggestions based on the ARCS Model to capture learners' attention.
    - Features such as gamification elements, interactive assessments, and storytelling tools will align with ARCS principles.
    - Educators will have access to analytics measuring engagement, relevance, confidence, and satisfaction levels in XR experiences.

7. TPACK Model:

The TPACK (Technological Pedagogical Content Knowledge) Model is a framework for understanding the complex interplay between technology, pedagogy, and content knowledge. It helps educators design effective learning experiences that integrate technology in a way that enhances learning. The TPACK Model can be used to ensure that XR experiences are designed to align with the learning objectives and content knowledge of the lesson [15].

- *Detailed Implementation:*
    - Tutorials and guides will assist educators in understanding the interplay between technology, pedagogy, and content knowledge.
    - The platform will provide a knowledge base with examples of effective TPACK integration in XR content.
    - Assessment tools will help educators evaluate the alignment of XR experiences with specific learning objectives and content knowledge.

8. LM-GM Model:

The LM-GM (Learning Mechanics - Game Mechanics) model is a framework for designing serious games. The model emphasises the connection between learning mechanics (LM) and game mechanics (GM), two essential components of serious games that should work together to create an engaging and effective learning experience [16].

- *Detailed Implementation:*
    - XR-authoring tools will include features for balancing learning mechanics and game mechanics in serious games.

- Templates and design guidelines based on the LM-GM model will be available, ensuring a harmonious blend of educational and gaming elements.
- Analytics dashboards will provide insights into the effectiveness of the LM-GM integration in achieving the learning outcomes.

9. GD-LLL-PE Framework (Game Design for Lifelong Learning Playful Experience):

Approaches playful experience design in the scope of learning contexts through two dimensions: Dimension 1 consists of 4 perspectives: User Experience, Gameplay, Storytelling and Learning, and Dimension 2 consists of 5 steps: Content & Learning Analysis, Game Design, pedagogical Integration, Play and Experience [17].

- *Detailed Implementation:*
  - The platform will guide users through each dimension and step of the GD-LLL-PE Framework.
  - Design modules within the platform will facilitate content and learning analysis, game design, pedagogical integration, play, and overall user experience.
  - A comprehensive dashboard will provide a visual representation of how each dimension contributes to the playful learning experience.

Note: The insights presented here are based on a systematic literature review conducted by Fernandes et al. in their work "Immersive Learning Frameworks: A Systematic Literature Review" [18].

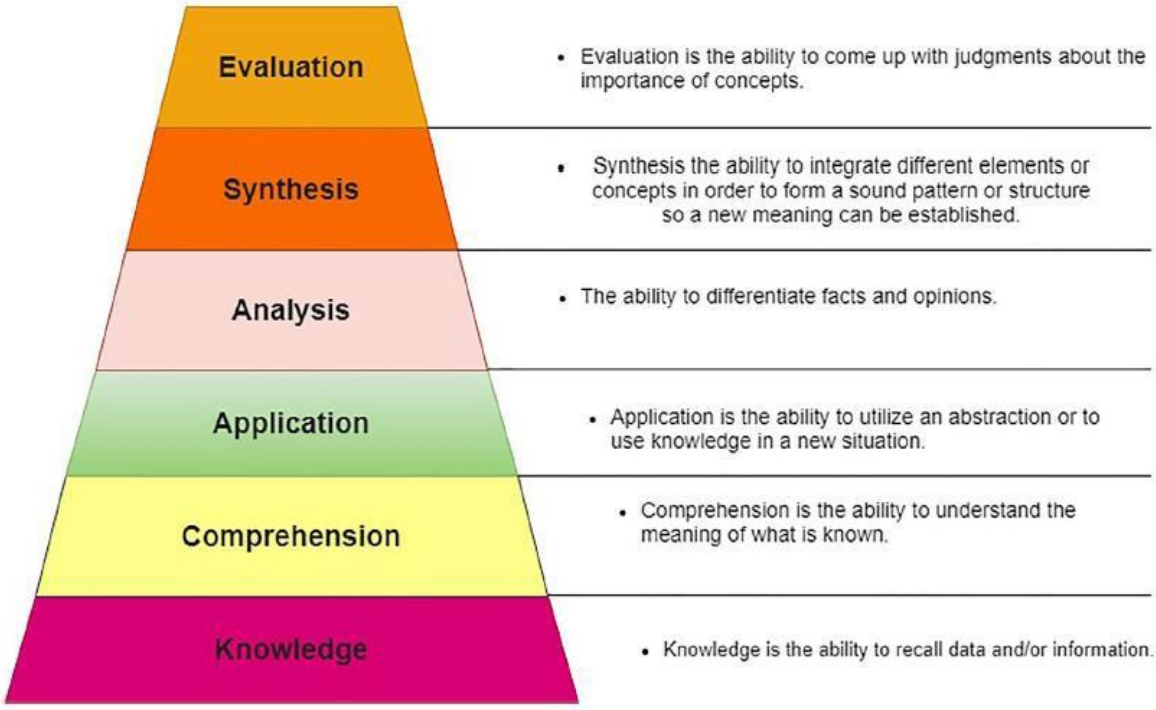

Figure 2: Bloom's Taxonomy with six categories [18]

4.3 XR Authoring Tools Using Educational and Learning Frameworks

There are several examples of XR authoring tools that have adopted these frameworks. Some characteristic examples of XR authoring tools that have adopted these frameworks are the following:

- **Unity3D**: Unity3D is a popular game engine that is also used to create XR experiences. It includes built-in support for educational and learning frameworks such as Bloom's Taxonomy (**Figure 2** and **Figure 3**) and the SAMR Model.
- **CoSpaces Edu**: CoSpaces Edu is an XR authoring tool designed specifically for education. It includes built-in support for the ARCS Model and the TPACK Model.
- **A-Frame**: A-Frame is an open-source web framework for creating XR experiences. It can be used with educational and learning frameworks such as Bloom's Taxonomy and the SAMR Model to create effective learning experiences.

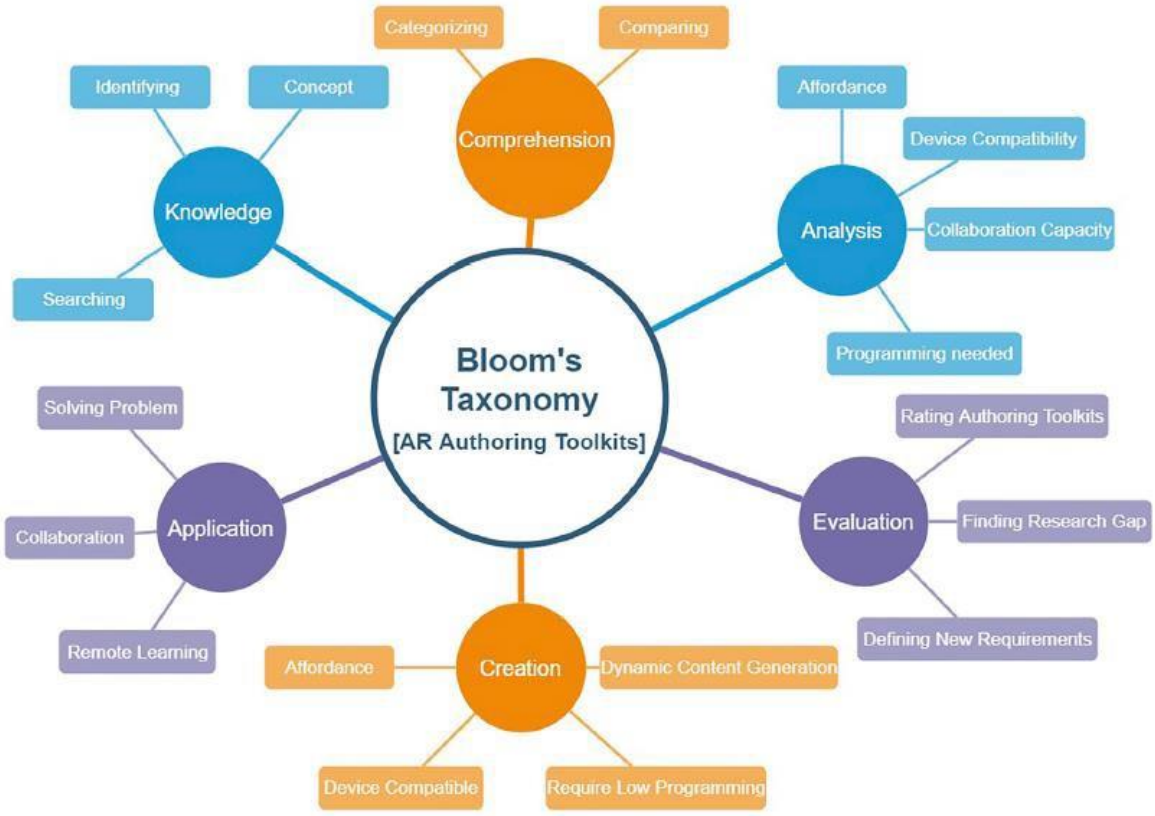

Figure 3: *Bloom's Taxonomy - From existing work to future goal of the project [18]*

5 XR4ED Potential Features

This section summarizes the set of features, with their most essential attributes, that will be provided by the XR4ED system to respond to: (a) the market imperatives identified, and (b) the needs expressed by the potential users. Before these features are implemented, in the next deliverable they will be validated through a set of interviews with experts. The table below is indicative and tries to examine status, priorities, risks and impact.

Requirements	Status	Priority/ Benefit	Risk Severity/ Likelihood/ Impact
FEAT1: Database			
FEAT1.1: Text information regarding product types (legal status, availability usage and costs).	Approved	Critical	High/ Low/ High
FEAT2: Data Input and Retrieval			
FEAT2.1: Data input should be seamless and automatic saving	Approved	Critical	Low/ Low/ High
FEAT2.2: Administration to create products or update	Approved	Critical	Low/ Low/ High
FEAT2.3: Seamless data retrieval and input to accommodate thousands of users	Approved	Critical	High/ Low/ High
FEAT3: User Interface			
FEAT3.1: User selection/input of current product usage and alternative selections (Monitor in which a user will add his/her input)	Approved	Critical	High/ Low/ High
FEAT3.2: User input regarding details such as type of technology (XR,AR,VR), education level (training, learning, etc) in order to be able to offer more customised suggestions regarding available tools.	Approved	Critical	High/ Low/ High
FEAT3.3: Dashboard providing an overview of the selection along with graphs/graphics showing results for a number of parameters related to the selection of products	Approved	Critical	High/ Low/ High
FEAT3.4: Registration page - automatic profile registration (through provision of email address and password) referring to specific details (name, date of birth, level of education, type of user etc.)	Approved	Critical	High/ High/ High
FEAT3.5: The user interface of the system shall be available in several languages, depending on the country of origin of the end-users. English will be the first languages supported by the system.	Approved	Important	Low/ Low/ High
FEAT3.6: The system should provide the option of developing new XR products to developers.	Approved	Critical	High/ High/ High

FEAT3.7: The system should allow educators to create new learning material using drag and drop fashion and other easy to use techniques.	Approved	Critical	High/ Low/ High
FEAT3.8: The system should allow the students to search, find and undertake different XR courses/ use XR learning materials.	Approved	Critical	High/ Low/ High
FEAT3.9: Shall enable developers to purchase XR software and upload their developments to the marketplace.			High/ Low/ High
FEAT4: User-Friendliness			
FEAT4.1: The system shall be user-friendly and easy to setup (SMS module, mobile software, and a web site)	Approved	Critical	High/ Low/ High
FEAT4.2: The system shall allow the customers to browse through related information with ease and comprehension.	Approved	Important	High/ Low/ High
FEAT 4.3: The system should enable users with cognitive disabilities, to use the system with assistive interface options.	Approved	Critical	High/ Low/ High
FEAT5: Accessibility			
FEAT5.1: The system should provide accessibility customization options such as voice-to-text for users with accessibility issues.	Approved	Critical	High/ Low/ High
FEAT5.2: The system should offer customization options regarding the size of the text, objects and elements.	Approved	Critical	High/ Low/ High
FEAT6: Ease of maintenance			
FEAT6.1: The system shall assist the administrators in maintaining the content information in the Database and Marketplace.	Approved	Important	High/ Low/ High

Table 4: *XR4ED Potential Features*

6 XR4ED Functional Requirements Specification

In this section we move on to defining more specific requirements that will need to be imposed on the solution so to build a system that conforms to those requirements and be certain that the system will deliver the features promised. In turn, since the features address one or more user needs, we will have addressed those needs directly in the solution.

Designing for XR applications is a complex task that requires knowledge from multiple disciplines in terms of interaction design, user experience, programming, and content creation. This complexity increases for educational XR, as it requires additional competencies in learning objectives because the activities designed need to fit the objectives that are to be achieved.

In general, requirements can be categorized as functional or nonfunctional. Functional requirements express an action that the system should perform and usually define both the stimulus and the response, or input and output. They tend to be more dynamic and often require more detail to clearly understand them. Use Cases are a powerful technique used for capturing and expressing detailed system behaviour. Non-functional requirements, the most common type of requirement, identify the things that the system can do, usually in response to external input.

6.1 XR4ED Functional Requirements

6.1.1 XR4ED Use Case

UC 1 – Use case name: Automatic Registration

Registration and access to the platform shall be easy and straightforward, using a valid email address, a selected username and password. The flow of events could be as follows:

- Register with an email, and a password.
- Automatic email sending with a link to verify the email.
- Automatic login to the platform to define the rest of the user's details.

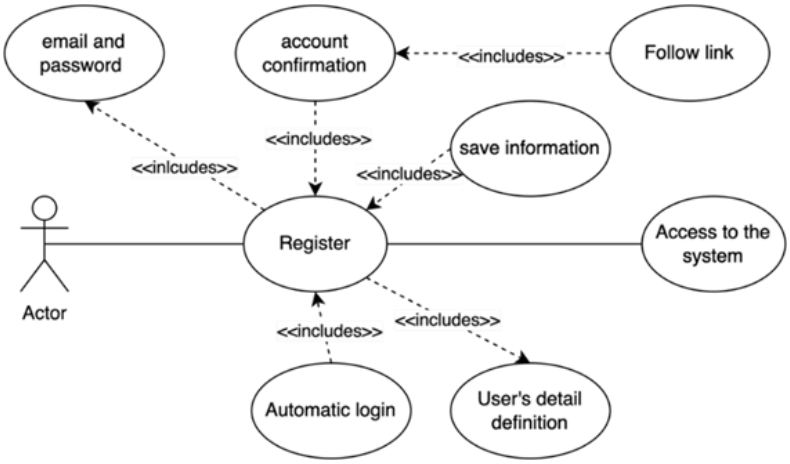

Figure 4: Use case 1: Automatic registration

UC 2 – Use case name: Lesson creation from Teaching staff

The teacher will log in to the system, with the purpose of designing XR relative lessons for students. Each teacher will use the drag and drop technique to select one of the following subjects:

- Virtual Field Trips applications
- Content Creation Application
- Awareness of Climate Change and Biodiversity challenges
- Training of Young Professionals
- Distance and Blended Learning
- Accessibility and Inclusion

The lessons will be available for the students and young professionals.

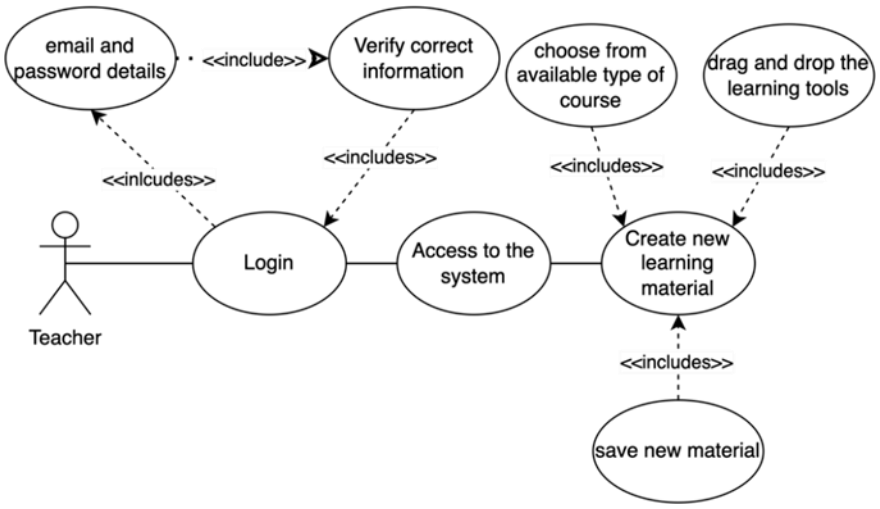

Figure 5: Use case 2: Lesson creation from teaching staff

UC 3 – Use case name: XR application development for XR developers

The XR Developer logs in to the system, with the purpose of creating new XR applications for education. The user enters the username and password correctly and enters the system. The user can see all the available XR tools and applications purchased by him, on the main screen. Using the drag and drop functionality, the XR developer can create new tools, and once they are satisfied, they save the current creation, and log out of the system. Later, they login again and they decide to upload their tool to the marketplace.

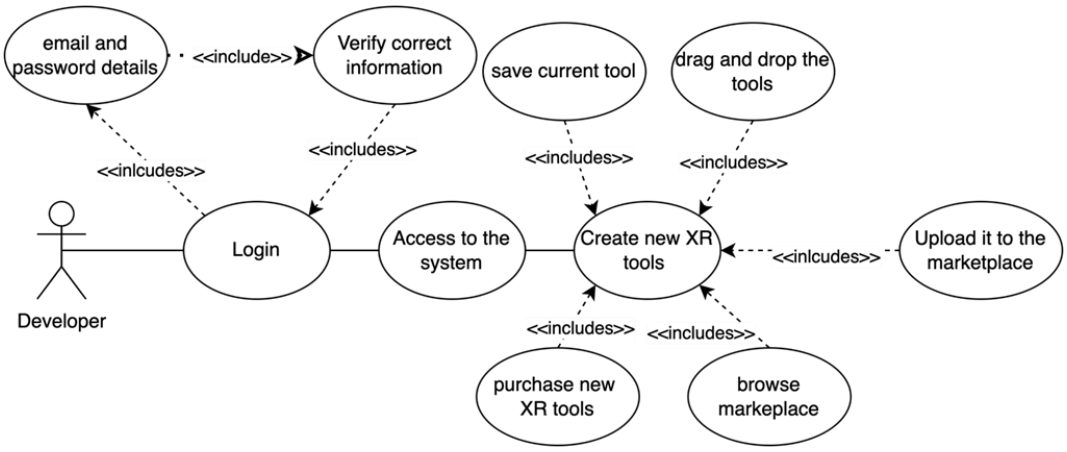

Figure 6: Use case 3: XR application development for XR developers

UC 4 – Use case name: STUDENT undertaking a learning course

The student logs in with their credentials to the system. Selects the learning course from the available, assigned courses:

- Virtual Field Trips applications
- Content Creation Application
- Awareness of Climate Change and Biodiversity challenges
- Training of Young Professionals
- Distance and Blended Learning
- Accessibility and Inclusion

The student selects the Virtual Field Trip. Moreover, the user selects which type of the system to load: light version (undertake the course through mobile phone, tablet or laptop) or heavy version (utilize additional XR equipment, e.g. XR glasses). The user selects the heavy version, connects the glasses and undertakes the course.

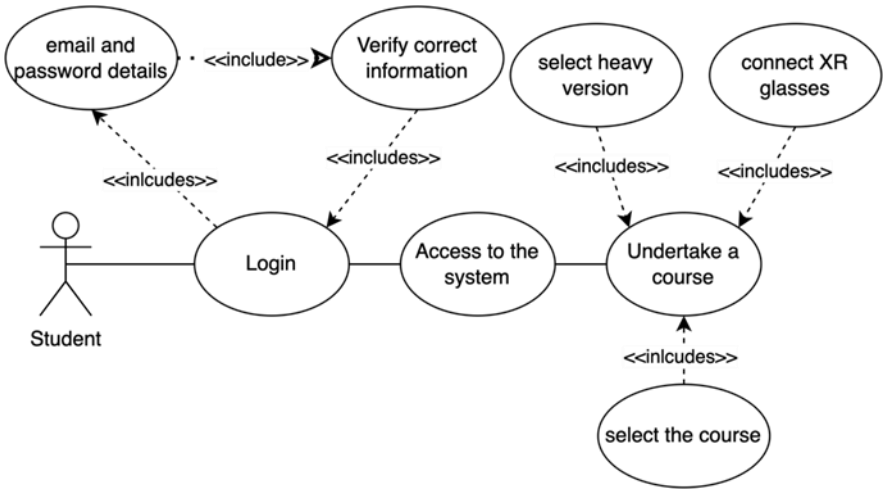

Figure 7: Use case 4: Student undertaking a learning course

6.2 Non-Functional Requirements

Non-functional requirements are presented below to serve as supplementary specifications to functional requirements. These requirements are used most typically to express some of the 'attributes of the

system' or 'attributes of the system environment' elements of our elaborated definition. The next section helps us to understand more about the XR4ED system we are going to build.

7 Environmental Requirements

XR technologies show great promise in creating immersive experiences that can rival real-life experiences. The COVID-19 lockdown necessitated students to explore alternative modes of learning beyond the traditional face-to-face classroom setup. However, each device and platform may have different requirements, so it is important to incorporate some specifications into development which were found important through literature research.

7.1 VR Platforms

When developing VR applications, it is crucial for developers to consider the type of experience they want to create. Currently, there are two main categories of VR devices that developers can target, and the primary difference between them is the type of tracking they use. 6 DOF (degrees of freedom) platforms support full positional tracking and usually require 360-degree tracking equipment to translate the user's movements into the virtual world in real time. On the other hand, 3 DOF platforms use orientation tracking and kinematic models to provide users with an immersive experience. Therefore, it is important for developers to choose the VR device that best aligns with the experience they want to create for their users. When developing a VR application, the first consideration for developers should be the type of experience they want to create. Currently, there are two categories of VR devices that developers can target, which primarily differ in the type of tracking they use. 6 DOF platforms offer full positional tracking, requiring 360-degree tracking equipment to accurately translate the user's movement into the virtual world in real-time. On the other hand, 3DOF (three degrees of freedom) platforms use orientation tracking and kinematic models to provide an immersive experience to users.

7.2 General User's Experience

The following are general guidelines for improving user experience in VR, specifically regarding user interaction with the virtual environment. These include providing users with the ability to set their own session duration, gently introducing users to the virtual world, and avoiding blank or frozen load screens.

There are a few reasons why VR mechanics can be problematic:

- The user may experience a real-world interruption, such as a phone call or someone entering the room and may need to take off the headset quickly.
- The user may want to take a break from an intense VR experience and come back to it later.
- The user may want to attend to notifications from other applications without exiting the VR experience entirely.

Use breaks - To provide a better user experience in VR, it is recommended to give users the option to save their progress in real-time and resume their experience at any point. It is also a good idea to remind users

to take breaks, especially if they are likely to lose track of time. Acclimating to a Virtual Environment - To facilitate user acclimation to a new virtual world or a new scene in a familiar virtual world, it is recommended to avoid presenting immediate instructions or choices. Users may struggle to process this information while still adjusting to their new environment, leading to cognitive overload. When introducing users to a new virtual environment.

Loading screens can be an unavoidable part of virtual reality experiences, but it is important to minimize their frequency and duration to enhance user engagement. It is recommended to avoid displaying a blank loading screen as users may become impatient and assume that the application has crashed, leading them to remove their headsets. Instead, consider using interactive loading screens that provide feedback to the user on the progress of the loading process. Furthermore, it is crucial to maintain orientation tracking and motion of the head during loading screens to avoid disorienting the user. This can be achieved by providing visual cues or maintaining the user's point of view during the loading process.

7.3 General user's environment

When designing for augmented reality (AR) experiences, it is important to consider several factors that impact the user experience. One key consideration is the user's movement and comfort. AR experiences often involve physical movement and manipulation of virtual objects, so designers should ensure that the user's movements are natural and comfortable. This can involve minimizing the need for awkward postures or excessive physical exertion and providing appropriate support or feedback mechanisms.

When designing for user experience in augmented reality, it is crucial to prioritize comfort and avoid placing the user in awkward or uncomfortable positions or movements. To achieve this, designers should minimize sudden or excessive movements and provide clear instructions when the user needs to transition between movements. Additionally, it is important to educate the user about specific movements or gestures that are required to trigger an experience and provide guidance on the necessary range of movement and any adjustments to the user's position or pose that may be needed.

Another important consideration is the environmental limitations and safety hazards. AR experiences often rely on environmental factors, such as lighting conditions or physical obstacles, which can affect the user's ability to perceive and interact with virtual objects. Designers should anticipate these limitations and design the experience accordingly by providing clear visual cues or adjusting the placement and size of virtual objects to accommodate real-world obstructions. Finally, designers must consider safety hazards that may arise from the use of AR technology, such as tripping hazards or distractions that could lead to accidents. Designers should prioritize user safety by designing intuitive and easy-to-use experiences, minimizing the risk of accidents, and providing appropriate warnings or safeguards where necessary.

8 Accessibility Requirements (accessibility and equity)

This section provides a comprehensive list of user needs and requirements for individuals with disabilities when utilizing XR. It begins by presenting a definition of XR, as used throughout this section, and then provides a brief overview of its various applications. The section discusses the intricate nature of understanding XR and highlights certain technical accessibility challenges, including the necessity for multi-modal support, synchronization of input and output devices, and customization. It further outlines the user needs pertaining to accessibility in XR and proposes subsequent requirements. Following that, it explores relevant prior work that can aid in comprehending the complex technical architecture and processes involved in constructing XR environments, serving as the foundation for a robust accessibility architecture. It should be emphasized that this section is explicitly not a compilation of fundamental requirements. Additionally, it is important to recognize that certain requirements may need to be implemented at a system or platform level, while others may be specific to content authoring.

8.1 Understanding Accessibility Challenges

Comprehending XR itself poses numerous technical challenges, encompassing hardware, software, and authoring tool issues. To create inclusive XR experiences, it is essential to understand interaction design principles, accessibility semantics, and assistive technologies. Yet, these complexities, which are considered fundamental, are already significant on their own. The most effective way to ensure that all users, including those with disabilities, can easily navigate XR environments is to create inclusive and ergonomic designs which take into consideration the differences many users may have in their abilities to experience different aspects of the technology. Those differences may include permanent, as well as temporary or situational limitations. Providing a comprehensive description of each disability is beyond the scope of this document. However, the general categories or types of disabilities to consider are as follows:

- Auditory disabilities
- Cognitive disabilities
- Neurological disabilities
- Physical disabilities
- Speech disabilities
- Visual disabilities

It is important when developing XR to understand the following aspects:

- Familiarity with specific user needs that may be related to multiple disabilities and require certain accommodations from the author or platform.
- Recognition of modality needs that may not be immediately apparent but still need to be supported in XR experiences.
- Availability of suitable authoring tools that cater to accessibility requirements in XR.
- Utilization of languages, platforms, and engines that incorporate accessibility semantics.

- Provision of accessible alternatives for content and interaction within XR environments.
- Implementation of specific commands within the VR environment, such as navigating directly to a specified location or following another user, to support different modalities.
- Integration of virtual assistive technologies, such as simulating a white cane through a haptic device, to provide non-visual feedback. Research has shown that using audio cues similar to those associated with a real-world infrared white cane can effectively assist users in centering themselves within virtual pathways and successfully navigating virtual doorways based on the same audio feedback as the physical device.

Understanding these considerations is crucial for XR developers to ensure the accessibility of XR environments. These requirements serve as a foundation for implementing accessibility best practices and bring together valuable advice for developers of platforms and applications to consider during their development processes. It is important to note that this guide does not aim to provide an exhaustive resource on designing for accessibility and inclusivity. We acknowledge that these best practices will constantly evolve and necessitate continuous input from relevant stakeholders, including standards-setting bodies that are actively working to establish industry standards for enhancing accessibility for individuals with disabilities.

Creating designs with an "average" user in mind can lead to rigid and limiting designs for all users, whereas inclusive designs often result in more adaptable and flexible technology. Inclusive design goes beyond simply making technology accessible to individuals with disabilities. Instead of developing separate experiences, tools, or plug-ins targeting specific disabilities, inclusive design aims to create a universal XR experience that integrates tools accessible to all users. Therefore, inclusive design should be a primary objective from the start, encompassing the platform and experiences across various applications utilized on the platform or app.

Incorporating inclusive functionalities such as vibration alerts, voicemail transcription, voice recognition, and haptic feedback has become standard in smartphones, providing benefits to all users, regardless of hearing or vision impairments. It is essential to integrate customizable designs and personalization options into the initial development process, enabling users to adapt their tasks and tailor their platform or application experience. This inclusive approach frequently leads to groundbreaking advancements that elevate the overall experience for all individuals involved.

8.2 General Accessibility Requirements

Accessibility in XR requires the creation of a flexible environment in which users can control the way they experience a platform or application. It is also important to remember that some users may have disabilities in more than one category.

8.2.1 Eliminating or minimizing background details and audio

Individuals with visual impairments or cognitive/intellectual disabilities may struggle to identify and prioritize significant experience options or tasks due to visually overwhelming backgrounds. Likewise,

individuals with hearing loss or cognitive/intellectual disabilities may find non-essential background audio confusing or disorienting. To address this, offering users the ability to remove or minimize background visuals and audio can help them focus on the most important activities or tasks within the application. Additionally, incorporating audio captioning features as an optional setting can further enhance accessibility, as discussed in the Visual Accessibility section of this chapter.

8.2.2 Undo/redo functionality

Including undo and redo functionalities in XR platforms and apps benefits all users, especially those with disabilities. It allows users to reverse or redo actions, helping individuals with physical, cognitive, visual, or auditory disabilities. For example, users with dexterity disabilities may make unintentional errors due to tremors or limited mobility. Additionally, a confirmation feature before executing actions helps users with disabilities rectify potential irreversible mistakes. Overall, these features enhance the accessibility and user experience of XR technology.

8.2.3 Decreasing speed and configuring action sequences

Users with mobility, vision, auditory, or cognitive disabilities may encounter difficulties in promptly and accurately responding to prompts, navigating options, or overcoming physical and reflex challenges. To facilitate user engagement and progress, it can be beneficial to provide options for adjusting the speed of the app or extending the time available for decision-making and completing challenges. Similarly, incorporating a pause feature in the app or game can assist users in setting up action sequences for tasks that involve multiple steps, ensuring they can respond accurately to each challenge.

8.2.4 Bypass Functions

XR experiences with physical or cognitive challenges can be difficult for users with disabilities. Timed tasks add pressure for those who cannot move or decide quickly. Adding a bypass function lets users skip challenging or timed experiences while still progressing. It benefits individuals with visual or hearing impairments too, allowing them to bypass frustrating or time-consuming tasks.

8.2.5 Saving progress

Allowing users to save their progress in an XR experience is advantageous. It helps with real-world interruptions, assists users who struggle with tasks, and allows them to end the experience when desired. For users with disabilities, it prevents the need to repeat challenging tasks by incorporating a progress-saving function. Developers should also consider adding options to skip or reduce the difficulty of tasks for improved accessibility.

8.2.6 Enhancing visual accessibility

The WHO (World Health Organisation) estimates that 1.2 billion people globally have vision impairment or blindness. Different types of vision loss, including low vision and color blindness, can affect engagement with XR apps. Challenges include reading overlaid text, visually busy backgrounds, and

reduced peripheral vision. However, with adjustable visual elements and text, vision loss should not hinder XR utilization and experience.

8.2.7 Adjusting the size of objects, elements, and text

Developers can empower low vision users in XR apps through customizable visual features, enhancing their experience and task completion. These features include magnification, font customization, contrasts, color adjustments, brightness controls, and peripheral maps. By implementing these visual customization options, developers greatly improve accessibility for low vision users, enabling more effective engagement with XR apps.

8.2.8 Enhancing audio augmentation and implementing text-to-speech technology

Audio augmentation, specifically text-to-speech (TTS) functionality, is crucial for users with vision loss in XR apps. TTS converts written elements into spoken words, ensuring comprehension and interaction. Developers can utilize existing TTS technologies available in operating systems and incorporate optical character recognition (OCR) to decipher words within images. Audio augmentation should also include object labeling for users to audibly identify elements. Integrating TTS and audio augmentation enhances accessibility and inclusivity for users with vision loss, enabling effective engagement with XR app content.

8.2.9 Applying color filters and utilizing symbols

To accommodate users who have difficulty discerning colors, developers should offer options such as allowing users to customize the interface and object colors, incorporating shapes or symbols alongside meaningful colors, or utilizing textures on objects or elements. These approaches assist users in distinguishing and comprehending information conveyed through color within the app.

8.2.10 Implementing scrim or scrim-like overlays

A scrim is a translucent layer that improves text readability against background elements without obstructing the view. It is useful for providing clear text and captions in programs that require legible display. Developers should be careful not to introduce color gradients that may hinder readability for users with vision loss. Scrims should enhance the user's experience and enable effective text reading without compromising the virtual environment.

8.2.11 Individuals who are deaf or hard of hearing

According to the WHO, around 5% of the world's population has auditory disabilities due to various factors. To ensure effective XR technology use for individuals who are deaf or hard of hearing, developers should provide multiple options to comprehend and manage audio features in XR platforms and apps.

8.2.12 Providing captioning for audio features

To ensure accessibility for people who are deaf or hard of hearing in XR technology, developers need to implement captions or subtitles for audio features. For readability, they should consider allowing users to choose the placement and making the captions moveable, providing options to adjust font type, colors of captions, and background colors, and indicating or labeling speakers in scenarios with multiple speakers. There are no specifically tailored captioning guidelines for XR, so developers should refer to those used in television broadcasting which cover things such as the number of characters per line, characters per second, punctuation standards, and more. While traditional two-dimensional captioning for media is relatively straightforward, creating three-dimensional captions for XR presents an additional challenge due to the unpredictable nature of a user's gaze and movements within the XR environment.

8.2.13 Utilizing icons to denote audio features

To help users understand the direction of audio in XR experiences, developers should add visual guides such as icons or captions to guide users in head movement or redirecting their attention. These signals should be clear and differentiated so that users can make sense of it and figure out where the audio is coming from. As an example, icons or captions in a game could signal the location of incoming gunfire or the approach of characters. NOTE: When making icons, developers should make sure to stay mindful of their cultural and regional significance so that unintended meanings are not implied to audiences in different parts of the world.

8.2.14 Sign Language

Developers should offer persistent sign language interpretation within apps, allowing users to customize its placement alongside captions and other visual elements. Users should have control over activating or deactivating features like captions, sign language interpretation, and background noise icons. Customization options empower users to tailor their experience based on individual needs, which is extremely important.

8.2.15 Mono Audio

Developers should add a stereo-to-mono audio switch to accommodate users with single-sided hearing loss. This feature combines both stereo channels into one, making it accessible through either ear. However, since mono audio lacks directional cues, developers should use icons or indicators to indicate sound direction. Many smartphones/tablets already have a "mono audio" option in their accessibility settings.

8.2.16 Individuals with mobility disabilities

Mobility disabilities impact a person's physical abilities, including walking, standing, using hands and arms, and controlling body movements. These disabilities can be caused by accidents, injuries, diseases, congenital conditions, or neuromuscular disorders. Challenges in virtual reality programs were identified as significant barriers for individuals with mobility disabilities. To improve accessibility, developers should consider the following options when designing XR programs.

8.2.17 Configurations and menu choices

Users with mobility disabilities should be able to configure their preferences during XR setup and save them for future use. Key preferences to consider are:

- Assisted Navigation: Provide app assistance for navigating and completing tasks.
- Separate Controller or Sensor: Include a separate controller or sensor for specific assistance.
- Seated or Stationary Access: Allow full content access from a seated or stationary position.

Further recommendations for XR accessibility:

- Slow Down Game or App Elements: Offer options to slow down cursor, camera movements, or zoom.
- Automation and Control Mapping: Enable automation of actions and mapping multiple actions to a single button.
- Remapping Controls: Allow remapping controls to alternate devices for accessibility.

These options align with existing software solutions for computer mouse usage to minimize errors for individuals with tremors or impaired precision. Developers can make XR applications more user-friendly for people with mobility issues by implementing strategies for multiple buttons or controllers.

8.2.18 Enhancing accessibility for individuals with mobility disabilities through dynamic foveated rendering and eye tracking technologies

Developers are integrating eye tracking and dynamic foveated rendering into XR hardware for improved performance and user experience. Foveated rendering reduces image quality in the peripheral vision while maintaining clarity in the focal point. Developers can utilize these features to enable users with mobility disabilities to interact with the interface using eye tracking. This enhances accessibility in areas like navigation, object selection, rendering quality, input selection, scrolling, aim assistance, and analytics. By incorporating these features, developers can greatly improve accessibility for individuals with mobility disabilities in XR applications.

8.2.19 Hand-tracking without the need for a controller

Developers can leverage controller-free hand-tracking hardware for accessible software. This technology benefits users with fine motor skill impairments or difficulty gripping buttons. Hand tracking enables natural interactions without physical controllers. Designing hand tracking software involves enabling both absolute and relative interactions for a comprehensive user experience. Some hardware developers provide guides to assist software developers in creating intuitive and accessible applications using hand tracking technology.

8.2.20 Cognitive Disabilities

Cognitive and intellectual disabilities cover various conditions like autism, learning disabilities (such as ADHD and dyslexia), Down Syndrome, brain injury, and dementia. These disabilities have a significant impact on cognitive functioning, learning abilities, and intellectual development.

8.2.21 The interconnectedness and multifaceted nature of solutions

A single solution can often have a positive impact on users with various disabilities. For instance, individuals with hearing impairments may not prefer speaking, so providing alternatives to speech-based command-and-control systems and in-game speech communications can benefit not only this community but also people with cognitive disabilities who struggle with speech or are non-verbal. It is crucial to enable these users to have control over their experience with the platform or app to avoid overwhelming them with sensory or information overload. One way to achieve this is by offering on-demand functions that assist users in orienting themselves within the experience and providing additional context about their progress in the app. These options should inform users about their current location in the virtual space, suggest next steps, and provide an overview of their app progress. In-app prompts, such as reminders, help topics, and introductions to new features, can be provided to support users in advancing through the experience.

Furthermore, offering training opportunities for users to experiment with interface and control configurations allows them to anticipate potential challenges and customize settings accordingly. For apps that involve challenges or tasks, it is beneficial to allow users to review their objectives, both completed and upcoming, to reorient themselves within the application and effectively progress. To enhance focus on essential information, users should have the ability to hide distracting or non-critical interface components, including visual, audio, and animated elements. If the design necessitates the use of separate controllers for tasks, users should be able to create control reviews for the interface, helping them navigate the controllers more accurately. Additionally, providing the option to reduce the number of controls can streamline the completion of objectives within the program.

8.2.22 Investigate world options

Enabling users, especially those with cognitive disabilities, to become acquainted with the app, its different interfaces, and input requirements can enhance their comfort level and active engagement with the program. This allows them to gain a better understanding of the interface, experiment with it, explore the environment, and establish their preferences before fully utilizing the app. For apps that incorporate challenge, puzzle, or gaming elements, this option also provides an opportunity for users to simply experience the app and its virtual world without feeling obligated to tackle challenges that might be too difficult or frustrating for them.

9 Compliance Requirements

9.1 Social and ethical concerns

XR technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), are becoming increasingly popular in the field of education. These immersive technologies offer new and exciting opportunities for teaching and learning, such as creating realistic simulations and providing hands-on experiences. However, as with any new technology, XR in education raises social, legal, and ethical concerns that need to be addressed [27].

From a social perspective, XR in education may exacerbate existing inequalities. Students from lower socio-economic backgrounds may not have access to the necessary technology, and the use of XR in the classroom may further widen the digital divide. Additionally, the use of immersive technologies may also have an impact on social interactions and interpersonal skills, as students may become more isolated and less able to communicate effectively in real-life situations.

From an ethical perspective, XR in education raises questions about the potential impact on student well-being. Immersive experiences can be overwhelming, and there is a risk of causing distress or trauma if the content is not appropriately curated and delivered. Additionally, there are concerns about the ethical use of XR technologies, such as the potential for manipulation or bias in the creation of virtual environments [28].

Despite the significant advantages of integration into the educational process of the outlined tools, there are several organizational problems, namely: it is necessary to train teachers and research and teaching staff, especially in the use of AR and VR in teaching disciplines, as well as in the development and implementation means of this type in the educational process.

Overall, while XR in education offers new and exciting possibilities for teaching and learning, it is essential to consider the social, legal, and ethical implications of their use. By addressing these concerns, we can ensure that XR in education is used responsibly and equitably to benefit all students.

Regarding social concerns, XR has gained significant attention and adoption in the field of education. While XR offers numerous benefits for education, there are also several social concerns that need to be addressed. Here are some of the social concerns regarding extended reality in education:

- **Accessibility**: One major concern is the accessibility of XR technologies. Not all students may have access to the necessary devices or internet connections required for XR experiences. This can create a digital divide, where students from disadvantaged backgrounds or with limited resources are unable to fully participate in XR-enhanced education, leading to potential inequalities in learning outcomes.
- **Privacy and Data Security**: XR technologies often involve the collection and processing of user data, including personal information and behavioural data. Privacy concerns arise when educational institutions or third-party service providers collect and store sensitive student data.

Ensuring robust data protection measures and obtaining informed consent from students and parents is essential to address these concerns.

- **Ethical Use of XR**: There is a need to establish guidelines and ethical practices for the use of XR in education. Educators and developers must consider the potential ethical implications, such as maintaining student safety, preventing inappropriate content, and promoting responsible use. Clear policies and frameworks should be in place to address issues like cyberbullying, harassment, or other forms of misconduct that may occur within XR environments.
- **Social Isolation**: While XR can provide immersive and engaging educational experiences, there is a concern that it may lead to increased social isolation among students. Physical interactions and social connections are crucial for holistic development, and excessive reliance on XR technology could potentially diminish face-to-face interactions, collaboration, and social skills development.
- **Equity and Inclusion**: It is essential to ensure that XR technology is implemented in an inclusive manner. Some students with disabilities or special educational needs may face challenges in fully accessing and benefiting from XR experiences. Education stakeholders must consider accessibility features, adaptability, and inclusive design principles to cater to diverse student populations.
- **Teacher Training and Support**: Integrating XR into educational settings requires adequately trained teachers who can effectively utilize the technology. Concerns arise when educators lack the necessary skills or training to leverage XR tools for teaching and learning. Providing comprehensive professional development programs and ongoing support to teachers is crucial to address these concerns.
- **Cost and Infrastructure**: XR technologies often require substantial investment in terms of hardware, software, and infrastructure. This can create disparities in access between well-funded schools and those with limited resources. Ensuring equitable access to XR tools and addressing the financial implications for educational institutions is an important consideration.

Addressing these social concerns requires collaboration between policymakers, educators, technology developers, and other stakeholders. Striking a balance between the benefits of XR in education and addressing these social concerns is crucial to ensure equitable, inclusive, and responsible implementation of extended reality technologies in educational settings [29].

9.2 Legal Concerns

From a legal perspective, there are concerns about data privacy and security. XR in education often requires the collection and storage of personal data, including biometric data, which raises questions about who has access to this data and how it will be used. Furthermore, there are potential legal liabilities associated with using XR in education, such as the risk of accidents or injuries during immersive experiences.

Regarding legal concerns, XR technologies present various legal concerns. Here are some common legal considerations associated with XR technologies. We are hereby numbering a list of legal concerns, while the specific legal landscape may vary based on the jurisdiction. It is crucial to consult with legal professionals every time an XR technology develops, who can provide updated advice tailored to the specific circumstances of such technology and the legislative framework following it:

- **Intellectual Property (IP) Rights**: Developers and creators of XR content should be aware of IP laws to protect their work. This includes copyrights for original content, trademarks for branding, and patents for novel inventions or technological advancements.
- **Privacy and Data Protection**: XR technologies often involve the collection and processing of personal data, such as user movements, behaviours, or biometric information. Companies must comply with applicable privacy and data protection laws, like the GDPR in the European Union, by obtaining user consent, implementing appropriate security measures, and providing transparent data practices.
- **Security and Safety**: XR applications may raise concerns regarding user safety and security, particularly in scenarios where users are fully immersed in virtual environments. Companies should consider potential risks and implement safeguards to protect users from physical harm or cybersecurity threats.
- **Content Regulation**: Depending on the jurisdiction, certain forms of XR content, such as violent or sexually explicit material, may be subject to regulation. It is essential for content creators and platform owners to understand and comply with local laws to avoid legal issues.
- **Consumer Protection**: XR technologies involve consumer transactions, such as purchasing hardware, software, or digital goods. Companies must adhere to consumer protection laws, including accurate advertising, fair pricing, warranty obligations, and refund policies.
- **Accessibility**: XR technologies should be accessible to individuals with disabilities, in accordance with accessibility laws. This includes considerations for hearing-impaired users, visually impaired users, and individuals with mobility limitations.
- **Jurisdictional Challenges**: XR technologies can be accessed and distributed globally, which may lead to conflicts regarding jurisdiction and applicable laws. Companies must consider the legal implications of operating across different regions and navigate potential conflicts accordingly.

9.3 Obstacles

In a similar context, there are several obstacles that need to be addressed to ensure that the development and uptake of XR technologies will continue to grow to their full potential.

First, awareness and acceptance of XR technologies among end-users, particularly professionals, remains low. There is also a lack of skilled professionals, in particular creators and developers, to cultivate and use XR solutions. Moreover, the lower awareness of what XR technologies are and how they

can be applied, coupled with the resulting lower demand and investment in XR, hinders the growth of XR companies in Europe.

What is more, the technical limitations of XR technologies make them difficult to scale. Many existing devices lack frictionless experience, advanced ergonomics, high precision, and realism. These limitations also spill over into health concerns such as simulation sickness and dizziness. Additionally, XR technologies do not always provide independent and inclusive access, raising issues of accessibility and usability.

Additionally, despite strong European research results in the XR domain, some areas, such as potential negative effects and ethical considerations regarding the use of XR, remain under-researched. In addition, insufficient research has been carried out in relation to sensory augmentation and neurophysiological changes, human-avatar relations, the integration of XR with AI, data protection issues, and the relationship between the features of immersive systems and learning performance.

Last, XR regulation and government policies can pose obstacles to the wider uptake of XR. Certain types of XR experiences collect and use large amounts of data (including personal data), posing ethical and privacy-related risks. The EU's strong personal data protection policy provides an advantage to Europeans, as it allows users to trust that their data is safe and could make them more willing to use XR solutions. However, uncertainty among practitioners about the application of General Data Protection Regulation (GDPR) and other regulations in relation to XR can impede its uptake. Additionally, the fragmentation of various healthcare systems across Europe is a barrier to using XR-based healthcare technologies in hospitals across different countries and regions. Each country often has a different healthcare model, and legal environments vary (e.g., in relation to the collection and storage of data), as well as different processes for the procurement, reimbursement, and use of digital health services [30].

To sum up, XR technologies are rapidly transforming sectors like education or healthcare. The European market for XR is projected to grow exponentially, indicating the importance of investing in the development and implementation of these technologies. As XR continues to advance and new use cases are discovered, XR will play a vital role in shaping the future of education, and beyond.

9.4 Guidelines

What is more, to protect and uphold ethical, legal and fundamental rights and sustainability considerations in the development and deployment of XR, policymakers should:

- Promote EU fundamental rights and encourage the adoption of ethics-by-design and ethics-by-default approaches.
- Broaden the scope of Article 9 of the GDPR by removing the purpose requirement for biometric data to be classified as special category personal data.
- Develop appropriate instruments to tackle and regulate harmful online content in XR technologies.

- Promote effective enforcement, monitoring and compliance with EU laws related to XR technologies, such as the GDPR, Digital Services Act (DSA), Digital Markets Act (DMA) and the proposed AI Act.

Regarding ethical concerns, XR technologies have the potential to greatly impact education. While they offer numerous benefits, there are also ethical concerns that need to be considered when deploying XR technology. Some relevant ethical concerns could be the following:

- **Accessibility**: One of the primary concerns is ensuring equal access to XR technologies for all students. Not all students may have access to the necessary hardware or stable internet connections, which can create a digital divide. It is essential to address these accessibility issues and provide equitable access to XR experiences.
- **Privacy and data protection**: XR technologies collect and process a significant amount of data about users, including their movements, behaviors, and interactions. There is a risk that this data could be misused, leading to privacy violations or the profiling of students. It is crucial to establish clear policies and guidelines to protect the privacy and data of students using XR technologies.
- **Psychological impact**: Immersive XR experiences can have a profound psychological impact on users, especially when used in educational settings. There is a need to consider the potential emotional and cognitive effects of extended reality technologies on students, particularly vulnerable populations. Care must be taken to avoid any undue stress, anxiety, or negative psychological experiences.
- **Bias and inclusivity**: XR applications and content should be developed with inclusivity and diversity in mind. There is a risk that biased or stereotypical representations could be perpetuated through XR experiences, reinforcing social inequalities or cultural biases. XR technology developers should prioritize designing XR content that is inclusive, culturally sensitive, and representative of diverse perspectives.
- **Ethical content creation**: Creating XR content for education involves making ethical decisions regarding the design, development, and deployment of these experiences. Educators and developers need to consider the educational value, accuracy, and appropriateness of the content. It is important to avoid misinformation, propaganda, or content that promotes harmful ideologies.
- **Over-reliance on technology**: XR technologies should be seen as complementary tools in education rather than a complete replacement for traditional teaching methods. Over-reliance on technology could lead to a reduction in human interaction, social skills, and critical thinking abilities. Striking a balance between XR and other pedagogical approaches is crucial to ensure holistic educational experiences.
- **Digital addiction and health concerns**: XR experiences can be highly engaging and immersive, which may raise concerns about addictive behaviors and potential health risks, such as eye strain, motion sickness, or cognitive overload. Educators and policymakers should establish guidelines for responsible and healthy use of XR technologies in educational settings.

To address these ethical concerns, it is important to have clear guidelines and policies in place for the ethical development, deployment, and use of extended reality technologies in education. Collaboration between educators, policymakers, developers, and other stakeholders is vital to ensure that XR technologies are used in an ethical, inclusive, and responsible manner.

10 Data and Security

10.1 Data Protection and Ethical Aspects

XR4ED project will pay particular attention to the protection of personal data, to maximize its utility in compliance with applicable legislation relating to the protection of personal data. It shall ensure that no data will be shared without ensuring legal compliance and calculating legal risks.

In the XR4ED Project all personal data processing will comply with EU legislative framework as well as national personal data laws and will follow the guidelines on "Ethics and Data Protection". It will be ensured that any partners, contractors or service providers that process research data at the XR4ED at partners' request and on their behalf will comply with the GDPR and the H2020 ethics standards.

10.2 GDPR Compliance

The XR4ED project shall ensure that personal data are protected according to the GDPR and that the use cases and experiments developed adhere to the GDPR.

In D2.1 and D2.3, the XR4ED project will present an analysis of the data subjects and the GDPR framework. These deliverables will include a comprehensive description of how the project implements GDPR regulations, along with information on the data subjects involved in testing and pilot operations, the types and sources of data that will be collected and processed, the data controllers and processors, and the processing activities of personal data that are taking place in the XR4ED platform.

Furthermore, these deliverables will highlight how the use of such technologies will protect the rights of both tested subjects and end-users (data recipients) in general. An analytical description will be included that outlines the measures taken to ensure the privacy and security of personal data, as well as how the project will comply with GDPR regulations.

As per the terms outlined in the DoA, it is stipulated that XR4ED will establish a team dedicated to data management and quality assurance, consisting of pre-existing security officers from the project stakeholders. The formation of this team will be overseen by the project coordinator, CYENS, and will comprise three Data Protection Officers (DPO) from among the partner organizations.

Moreover, according to Article 4 of the EU GDPR, the Data Controller, the Data Processor and the Data Recipient are defined as follows:

- Controller – "means the natural or legal person, public authority, agency or other body which, alone or jointly with others, determines the purposes and means of the processing of personal data".
- Processor – "means a natural or legal person, public authority, agency or other body which processes personal data on behalf of the controller".

- Recipient – "means a natural or legal person, public authority, agency or another body, to which the personal data are disclosed, whether a third party or not".

It is critical to safeguard GDPR compliance when employing XR technology in an educational setting. Here are some important considerations to be addressed when developing such technology:

- Get unambiguous and informed consent from every user engaged, such as students, instructors, or parents/guardians if minors are involved. Describe the goal and extent of data gathering and processing.
- Data minimization entails collecting and processing just the personal data required for the intended educational goals. Avoid collecting or retaining an excessive amount of data.
- Implement adequate technological and organizational safeguards to protect personal information from unauthorized access, loss, or disclosure. Encryption, access limits, and frequent data backups are all part of this.
- Limitation of Purpose: Ensure that personal data gathered by XR technology is only utilized for educational purposes and not for other unrelated activities without further authorization.
- Data Transfers: If personal data are moved beyond the European Economic Area (EEA), ensure that suitable measures are in place, such as Standard Contractual Clauses or Binding Corporate Rules, as updated.
- Data Retention: Establish proper data retention periods and remove personal data when it is no longer required for educational reasons or when an individual request that it be erased.
- Privacy rules: Provide clear and transparent privacy rules that clarify how personal data in the XR educational project is collected, handled, and shared.
- Vendor Compliance: If you engage with third-party XR technology or service providers, be sure they are GDPR compliant and have adequate data protection mechanisms in place.
- Data Protection Impact Assessment (DPIA): Conduct a DPIA to identify and remedy any possible data protection issues.

10.3 Privacy By Design and Privacy by Default

The concept of "Privacy by Design" can be summarized as the integration of data protection measures into the design of technological solutions, upon its development. The idea is that data protection is most effectively implemented when it is built into technology from the outset. Data protection by design is one of the best ways to address the ethical and legal concerns that arise within a research Project. Data processing must be lawful, fair and transparent. It should involve only data that is necessary and proportionate to achieve the specific task or purpose for which they are collected.

In the case of XR4ED, all XR solutions will be developed with a "privacy-by-design" approach. This means that privacy and data protection will be considered and prioritized from the very beginning of the project and will be maintained throughout the entire lifecycle of data processing activities.

Privacy by Default means that once a product or service has been released to the public, the strictest privacy settings should apply by default, without any manual input from the end user. In addition, any personal data provided by the user to enable a product's optimal use should only be kept for the amount of time necessary to provide the product or service. If more information than necessary to provide the service is disclosed, then "privacy by default" has been breached. We aim to build and disseminate XR4ED in such a way in order to comply with the Privacy by Default rule as well.

The XR4ED project partners are committed to collecting only the necessary data to achieve the research goals. Data sharing will be restricted to health-related information that is essential for scenario testing purposes.

Moreover, when collecting personal data, it is both a legal and ethical responsibility to ensure that the privacy and rights of participants are safeguarded. This is crucial in mitigating potential ethical risks associated with data processing. In the XR4ED project, data security measures will be implemented at all levels to ensure the protection of participants' information.

10.4 The Anonymization Principle

Anonymization is the process of rendering personal data anonymous. an identified or identifiable natural person or personal data rendered anonymous in such a manner that the data subject is not or no longer identifiable. When anonymizing personal data the natural person cannot be identified therefore GDPR does not apply.

10.5 Remarks

In conclusion, the development of extended reality (XR) technology for education brings about a range of ethical, social, and legal concerns. While XR offers immersive and engaging learning experiences, it is crucial to address these concerns to ensure responsible and beneficial implementation. Ethically, developers must prioritize user privacy, data security, and informed consent. Socially, considerations such as accessibility, inclusivity, and potential impact on interpersonal interactions must be taken into account. Legally, intellectual property rights, copyright issues, and regulatory compliance should be carefully navigated. By addressing these concerns, among else as highlighted above, through transparent policies, stakeholder collaboration, and ongoing evaluation, XR technology can be leveraged responsibly to enhance education while mitigating potential risks. The partners of XR4ED aim to develop it taking into consideration the need for compliance with the above frameworks and abidance by certain guidelines to address the above concerns.

11 Hardware, Software and User Interface Requirements

The initial hardware, software and user interface requirements were internally discussed and will need to be validated through the interviews in the next deliverable.

11.1 Hardware Requirements

- VR Capable Laptop/PC with at least 16-32 GB RAM to load bigger VR environments.
- VR Headset supported by Unity and SteamVR
- GPU: GPUs from NVIDIA or AMD, with dedicated VR capabilities such as NVIDIA GeForce RTX series or AMD Radeon RX series, are recommended.
- Storage: At least 3-4 GB free storage
- Peripherals if required by the custom environment/Application created by a developer.
- Internet connection of at least 100 Mbps.

11.2 Software Requirements

- VR Device specific software such as Oculus Connect
- Preferably Steam and SteamVR
- Windows 10 or above
- Drivers for specific VR devices if required.

11.3 User Interface Requirements

- Layout and Design: Maintain visual coherency between the XR4ED application.
- Navigation: Use the standard navigation defined by the VR Headset or XR4ED specifically as much as possible.
- Input and Output: Use the standard Input and output buttons defined by the VR Headset or XR4ED specifically as much as possible.
- Visual Feedback: Provide visual feedback to users, such as highlighting selected items, showing loading indicators, or indicating errors or warnings.
- Accessibility: UI requirements consider accessibility guidelines to ensure the application is usable by individuals with disabilities.
- Localization and Internationalization: Address the need for localization and internationalization.

12 Assessment Requirements

12.1 Overview

XR offers immersive assessment experiences that closely simulate real-world activities. However, current assessment practices in virtual environments often rely on external instruments administered separately. This review examines literature on assessment types in XR, focusing on methods for evaluating skills, work products, performance, and analyzing log files. Conventional assessments like pre and post tests, multiple-choice items, short answer items, and open-ended questions are commonly used to measure learning effectiveness in virtual environments. For example, [20] developed a self-designed content test to assess science inquiry and process skills in the virtual environment called River City [21].

Performance metrics can include assessing the number of questions asked within and outside the XR lab experience, providing additional performance measures. Evaluating learner-created work products within immersive virtual environments allows for authentic assessment of learner performance. Rose (1995) employed information processing and constructivism theories to identify approaches for measuring learning in VR, including performance tasks like world-building, problem-solving, and evaluating the quality of final products [21].

In a study by [22] learners in a Second Life course were required to create a summative assessment that accurately depicted a biological molecule or bioinformatic concept. These work products can be evaluated using rubrics, scoring guides, or automated procedures [23]. The Virtual Performance Assessment (VPA) Project, developed by the Harvard Graduate School of Education, offers an open-ended 3D immersive virtual environment for performance assessments in science inquiry skills.

Students engage in authentic inquiry activities, solve scientific problems, and interact with non-player characters (NPCs) to gather data and conduct experiments [24]. VPA allows for automated collection of process data (event logs and behaviors) and product data (students' final claims), facilitating assessment of science inquiry [25]. These examples demonstrate progress in assessing learning within virtual environments.

Automated evaluation of log files is an emerging frontier in educational assessment. Log files capture learner interactions and data in the background as they navigate through XR experiences [26]. Stealth assessment, a form of log file analysis, detects and characterizes meaningful patterns and features of learner work as observations without disrupting the XR experience [23]. Stealth assessments offer the advantage of collecting data seamlessly during learner engagement [21].

12.2 Assessing Learning Outcomes

Teachers must evaluate the extent to which students have acquired new knowledge from their lesson plans and curricula, regardless of the source, whether it be books, videos, interactive technologies, immersive technologies, or other materials. Some educators choose to create assessment tools or tests

external to the XR app they use to enhance their lessons. Others may prefer to gain insights into student learning or have students' complete assessments within the XR app itself.

Furthermore, developers need to take into account that there is currently no universally available third-party software for classroom management that enables teachers to monitor a student's VR session and ensure both task adherence and physical safety. Nevertheless, it is crucial for teachers to ensure students' active involvement in the activity and be aware when students deviate from the intended application usage. Developers should consider incorporating casting or streaming capabilities where possible. Additionally, developers should be mindful of the financial constraints in educational settings, which often restrict the number of students who can engage in immersive experiences simultaneously.

12.3 Recommendations

- Developers should consider granting administrative privileges to teachers within the apps, enabling them to monitor students' engagement by providing information on the duration of time spent on each aspect of the experience. This should include identifying instances where a student may have missed or skipped a part of the activity.
- To accommodate the varying levels of student participation, it is important to design both collaborative and individual experiences that align with the educational requirements of the curriculum and classroom. This could involve creating asynchronous cooperative experiences that can be tailored to support specific learning objectives.
- To enhance teacher oversight, developers should contemplate implementing casting or streaming functionalities. This would allow teachers the opportunity to observe and assess the students' level of engagement during the immersive experience.

13 Documentation Requirements

The XR application should be fully documented, with clear instructions for installation, setup, and use, as well as user guides and technical support resources.

For teachers and educators, the documentation should be tailored to their specific needs and requirements. Here are some considerations for documentation in XR systems targeted towards teachers and educators:

- **Pedagogical Guidelines**: Provide guidelines and best practices for integrating XR into educational settings. This can include suggestions on how to design XR experiences that align with specific learning objectives, how to facilitate classroom discussions around XR content, and how to evaluate student progress or engagement within XR environments.
- **Lesson Plans and Curriculum Integration**: Offer sample lesson plans or ideas for incorporating XR into the curriculum. Provide educators with suggestions on how XR experiences can be integrated into different subjects or topics, along with guidance on how to effectively use XR as a teaching tool or for student projects.
- **Assessment and Feedback**: Educators may need guidance on how to assess student learning and progress within XR experiences. Documentation should include suggestions for formative and summative assessment methods specific to XR, as well as guidance on providing feedback and evaluating student work within virtual environments.
- **Content Creation and Customization**: Teachers and tutors might want to create their own XR content or customize existing content to align with their teaching goals. Provide documentation on tools, platforms, or resources that allow educators to create or modify XR experiences, including guidelines for content creation, asset integration, and scripting if applicable.
- **Collaboration and Classroom Management**: If the XR system allows for collaborative experiences or multiple users in the same environment, documentation should provide guidance on managing and facilitating collaborative activities within XR. This can include instructions on how to create group sessions, assign roles, monitor student progress, and manage classroom interactions.
- **Professional Development Resources**: Offer additional resources, such as webinars, video tutorials, or case studies, that support teachers and tutors in their professional development journey with XR. These resources can help educators enhance their understanding of XR technology, explore innovative teaching methods, and connect with a community of educators utilizing XR.

When targeting teachers and tutors, it is crucial to emphasize the educational benefits of XR and provide practical guidance that aligns with their teaching objectives. Collaboration with educators, educational technology experts, and instructional designers can contribute to developing documentation that addresses the specific needs and challenges faced by teachers and tutors in leveraging XR effectively for educational purposes.

For students (over 18 years old), the documentation should focus on providing them with the necessary information to effectively engage with the XR experiences and maximize their learning outcomes. Here are some considerations for documentation in XR systems targeted towards adult students:

- **Getting Started Guide**: Provide a clear and concise getting started guide that walks students through the initial setup process, including XR device setup, software installation, and account creation. This guide should cover the basics of navigation and interaction within the XR environment.
- **Learning Objectives and Benefits**: Clearly outline the learning objectives and potential benefits of using XR in the educational context. Explain how XR experiences can enhance understanding, promote critical thinking, and provide immersive learning opportunities. Emphasize the specific advantages of XR over traditional learning methods.
- **Navigation and Controls**: Provide detailed instructions on how to navigate and interact within the XR environment. Explain the functionality of various controls, gestures, or input devices. Ensure that students understand how to move within the XR space, manipulate objects, access menus or information, and perform actions relevant to the educational context.
- **Content Catalog and Exploration**: If the XR system provides access to a catalog of educational XR content, create a catalog guide that showcases available experiences, their topics, and their relevance to the curriculum. Help students explore and discover relevant content, providing suggestions for different subject areas or topics.
- **Learning Activities and Assignments**: Offer guidance on how to engage with XR experiences as part of learning activities and assignments. Provide instructions on how to complete specific tasks, exercises, or assessments within the XR environment. Include examples or case studies that demonstrate the integration of XR into various disciplines.
- **Troubleshooting and Support**: Include a troubleshooting section that addresses common issues students may encounter while using the XR system. Provide step-by-step instructions to troubleshoot problems related to connectivity, software performance, or user errors. Offer contact information or access to a support community for additional assistance.
- **Privacy and Safety Considerations**: Inform students about privacy and safety aspects of using XR. Explain any data collection practices, if applicable, and provide instructions on how to protect personal information within XR experiences. Emphasize the importance of taking breaks, maintaining physical safety, and adhering to guidelines for responsible XR usage.
- **Community and Collaboration**: If the XR system supports collaboration or interaction with other students, provide guidelines on how to join collaborative sessions, communicate with peers, and engage in group activities within the XR environment. Encourage students to explore collaborative learning opportunities and provide suggestions for effective collaboration within XR.

Remember to use language and terminology that is appropriate for adult learners. Provide documentation that is concise, accessible, and visually engaging, leveraging images, diagrams, or videos to enhance understanding. Regularly update the documentation to align with any system updates or changes.

14 Questionnaire Results

Results from the questionnaires is split into 2 sections: experts and students. An overview of the outcome is provided in the next sub-sections.

14.1 Experts

Among the 48 experts who participated in the survey, 10 were female. The age distribution of the sample is displayed in **Figure 8**. The median duration of XR technology usage in the sample was 5 years, while the median reported usage of XR technologies was "Sometimes".

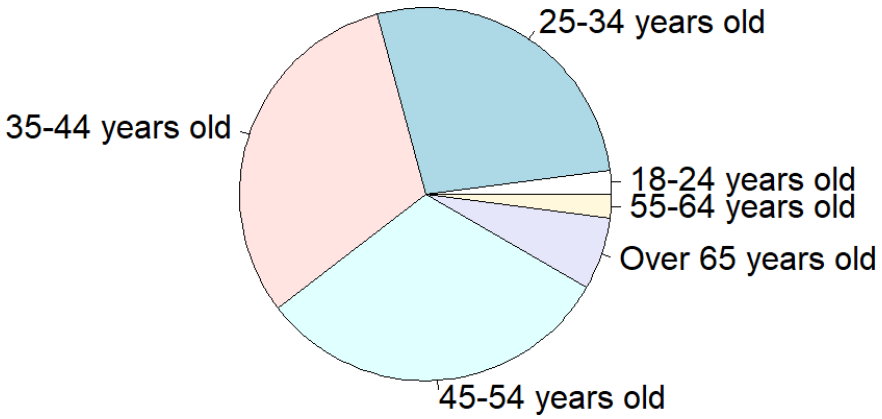

Figure 8: Age distribution of the expert survey sample

Participants predominantly perceived themselves as "Aware" (median 4; 1 = Unaware, 5 = Very aware) of the current use of XR technologies for educational purposes (see **Figure 9** for more details).

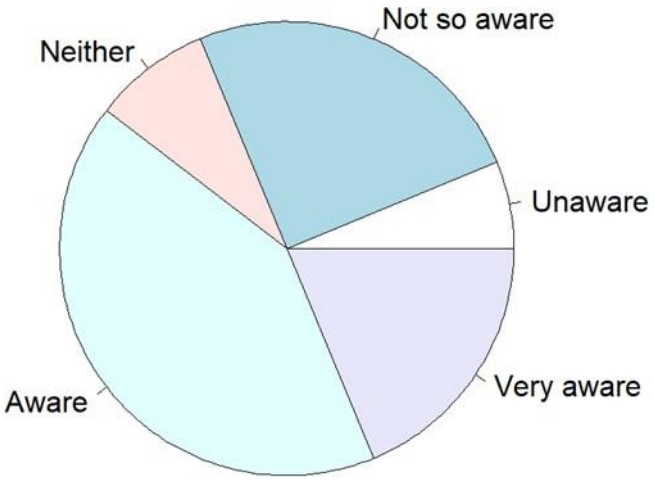

Figure 9: *Responses to How aware are you of the current use of XR (AR, VR, MR) technology for educational purposes*

Participants rated themselves as mostly perceptive in the ability to program or design new educational tools based on information and communication technologies (median 4; 1 = Very imperceptive, 5 = Very perceptive). The median level of knowledge about XR was slightly above average (median 3.5; 1 = Very poor knowledge, 5 = Very good knowledge).

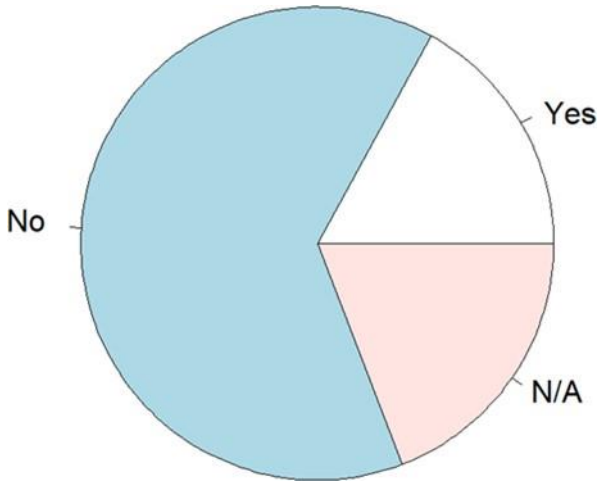

Figure 10: *Responses to Do you feel that you have received sufficient training at your university on the possible applications of XR (AR, VR, MR) in education?*

The majority of experts in VR, AR, and MR who completed the survey did not have experience using the technology to assist in education (30 No, 16 Yes, 2 N/A). However, most of the sample admitted not receiving sufficient training on the possible applications of XR at their university (**Figure 10**).

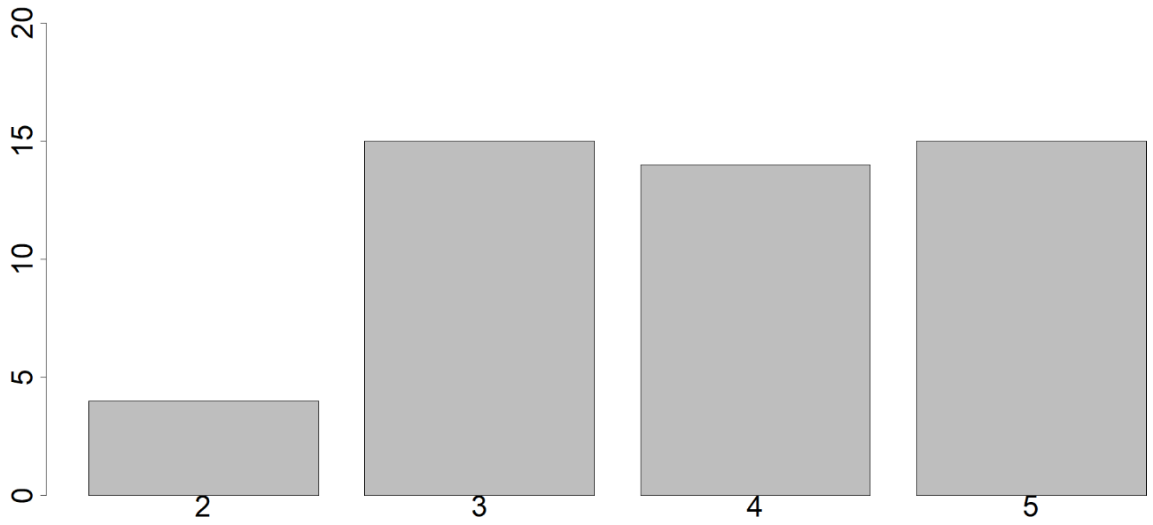

Figure 11: *Responses to Rate from 1 to 5 the level of importance you give to the didactic usefulness of XR (AR, VR, MR) when designing an educational experience*

The median rating given by participants regarding the level of importance they assigned to the didactic usefulness of XR (**Figure 11**) when designing an educational experience was 4 (1 = Unimportant, 5 = Very important), suggesting high importance.

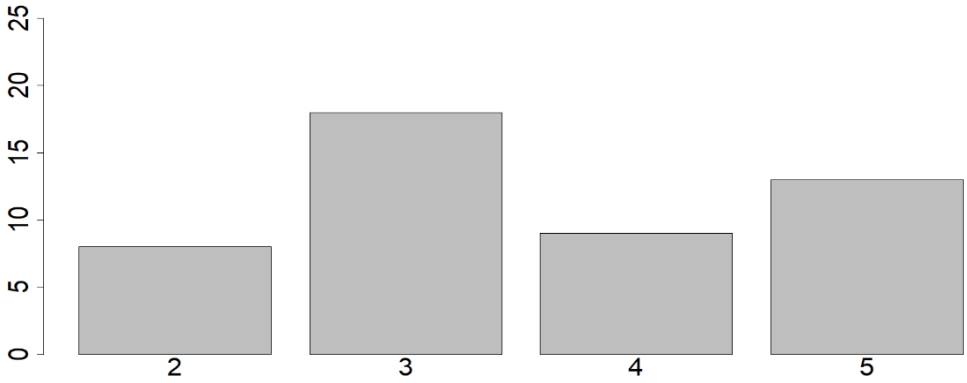

Figure 12: *Responses to Please rate the level of importance of the following technical aspect of XR (AR, VR, MR) when designing a XR (AR, VR, MR) educational experience: Realism*

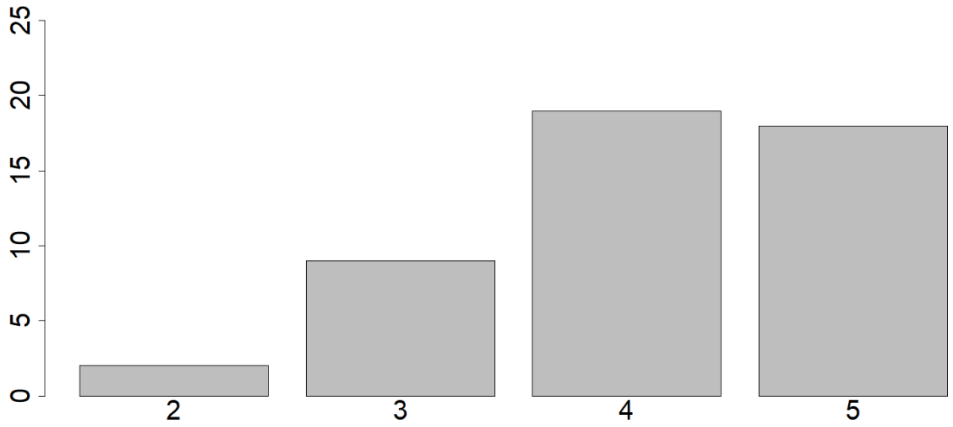

Figure 13: Responses to Please rate the level of importance of the following technical aspect of XR (AR, VR, MR) when designing an XR (AR, VR, MR) educational experience: Immersiveness

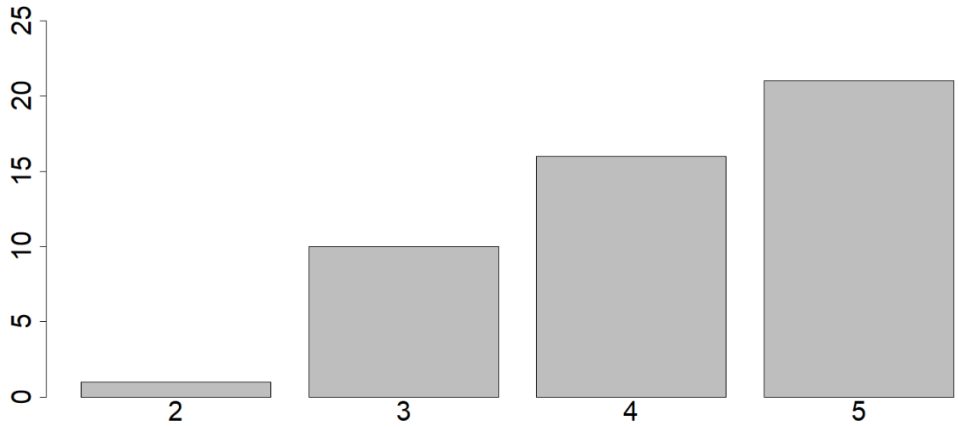

Figure 14: Responses to Please rate the level of importance of the following technical aspect of XR (AR, VR, MR) when designing an XR (AR, VR, MR) educational experience: Three-dimensional design

From the surveyed three aspects of XR – realism, immersiveness, 3D design (see **Figures 12, 13, 14**) – participants tended to be the least concerned with realism (median 3). Both 3D design and level of immersion received a median response of 4, indicating the importance of these aspects.

The expert participants expressed considerable confidence (median 4; 1 = Not at all confident, 5 = Extremely confident) in the belief that XR can assist in most aspects of education. These aspects

included factual knowledge transfer, workflow familiarization, procedural training of high-risk or high-cost activities, flexible off-site and remote content delivery, effective education of a large number of students from different degrees, standardized delivery of knowledge to university/school students, and standardized assessment of knowledge to university/school students.

The majority of experts (36 participants) indicated that they would develop an XR teaching tool within their course (without considering practical implementation issues), while only 2 participants answered "no". The remaining 10 participants did not respond due to not being involved in teaching.

Some expert participants perceive XR partially as a passing trend (15 participants), while most do not view it as a passing trend (18 participants). However, they seem to have an experience or belief of high acceptance of XR as a teaching resource (**Figure 15**).

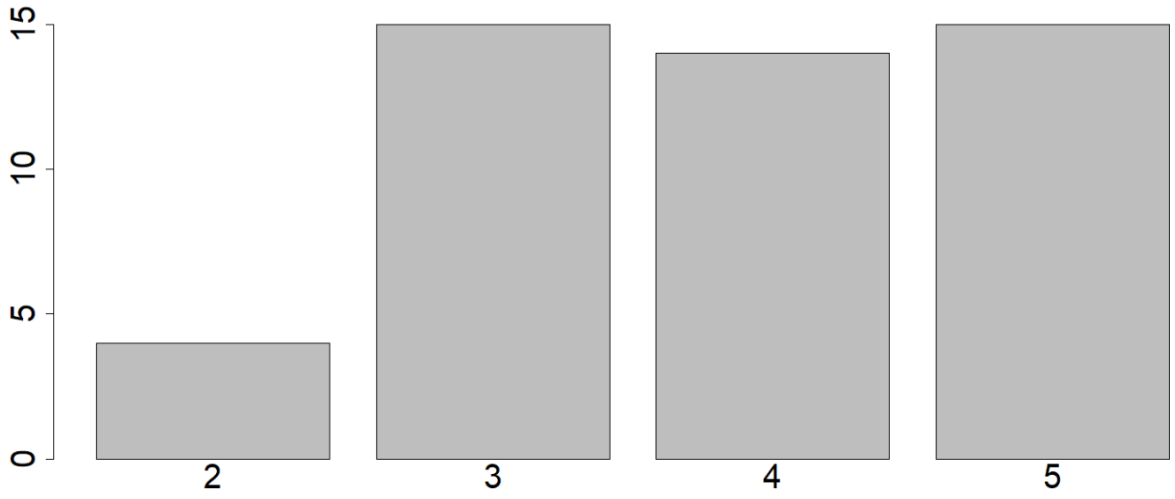

Figure 15: *Responses to Rate from 1 to 5 the possible level of acceptance of XR (AR, VR, MR) as a teaching resource that you think your students have (or would have).*

Experts also tend to believe that XR will become a standard tool for facilitating the transmission of knowledge within university environments (median answer 4 = Likely). Similarly, experts mostly agree (**Figure 16**) that offering XR content will influence how current and future students perceive a university's ability to provide a progressive and modern teaching environment (median answer 4 = Likely).

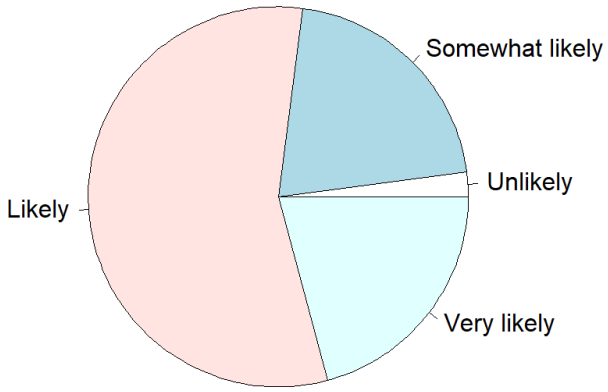

Figure 16: *Responses to 'In your opinion, how likely is it that offering XR (AR, VR, MR) content will influence how current/future students think about university's ability to offer a progressive modern teaching environment? '*

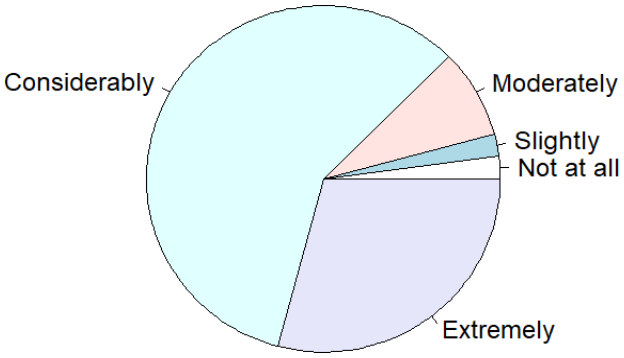

Figure 17: *Responses to XR is a powerful tool and should be used in teaching within educational environments*

The surveyed sample of experts in XR considerably agree with the statement, that „XR is a powerful tool and should be used in teaching within educational environments" (median 4 = Considerably agree), with the second most selection option „Extremely considerably" (see **Figure 17**).

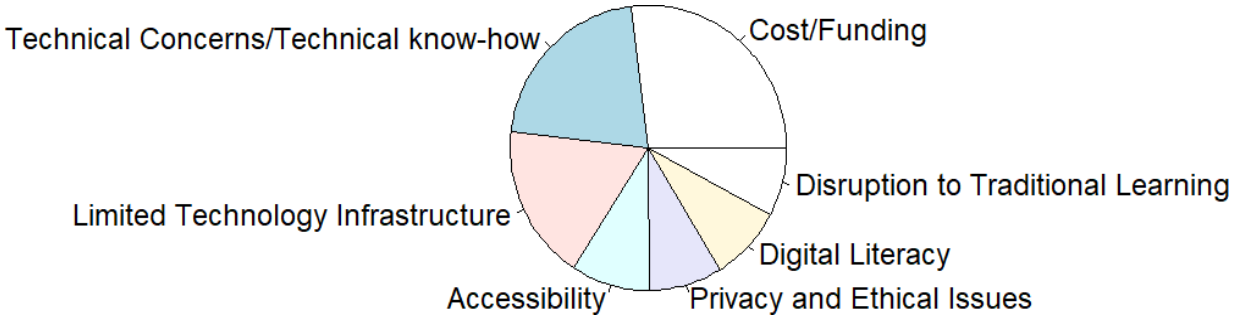

Figure 18: *Responses to Where do you see the biggest barriers for implementation of XR (AR, VR, MR) technologies within the next 5 years at the universities/schools?*

The major barriers for implementation of XR technologies in schools and universities are cost/funding (38 participants), technical concerns/technical know-how (30 participants), and limited technology infrastructure (25 participants). On the other hand, the least number of participants believe that the disruption to traditional learning is a barrier (11 participants). Full details are in **Figure 18**.

14.2 Students

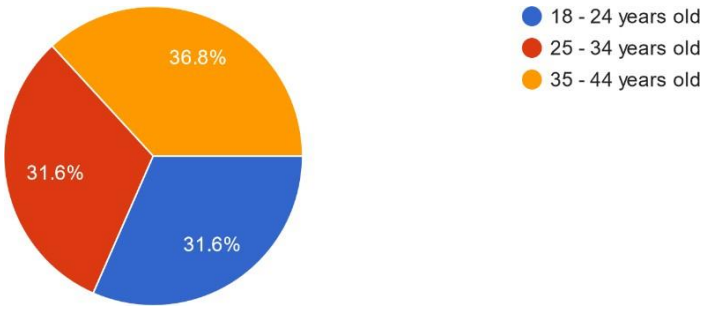

Figure 19: *Age distribution of the student survey sample*

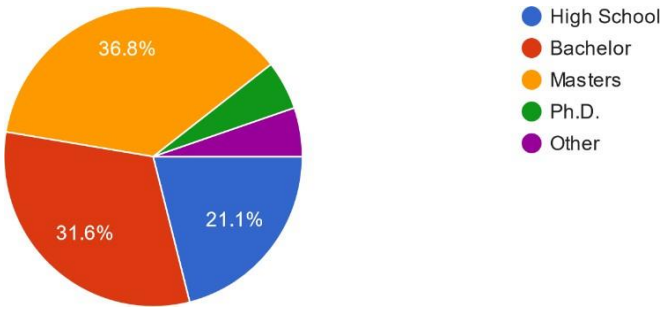

Figure 20: *Education in the student survey sample*

From the 19 student participants (8 female), 6 have already used XR in the school courses. The age and education distribution of the sample can be seen in **Figures 19, 20**.

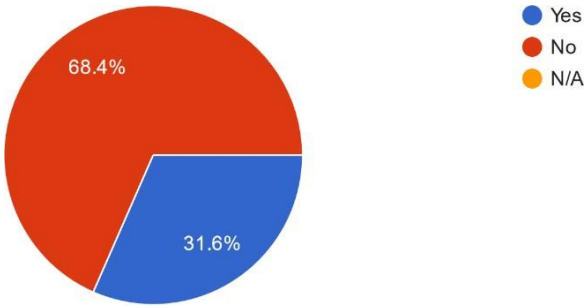

Figure 21: *Responses to Have you used XR technology (either VR, AR or any other) in any of your courses?*

Student participants mostly did not use XR in any of their school courses (**Figure 21**). However, 84.2% of the students would select a course that offers XR (AR, VR, MR) technology as a teaching tool over a similar course without it (**Figure 22**) and 57.9% would select a course that offers XR (AR, VR, MR) technology as a teaching tool even though they might not be overly interested in the course content as a whole (Figure 16). 52.6% of participants also have some concerns about using XR in lectures; such as creating an unequal experience based on the accessibility of the equipment, losing interaction with other students, or creating distractions in classes.

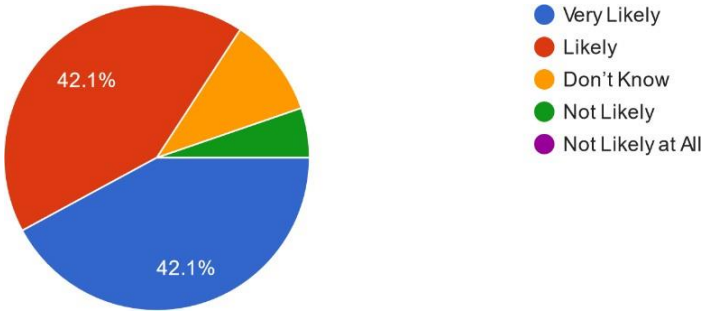

Figure 22: *Responses to How likely are you to select a course that offers XR (AR, VR, MR) technology as a teaching tool over a similar course without?*

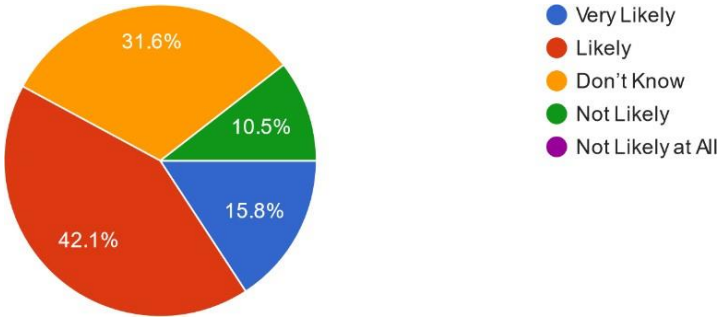

Figure 23: *Responses to How likely are you to select a course that offers XR (AR, VR, MR) technology as a teaching tool even though you might not be overly interested in the course content as a whole?*

16 participants expected XR (VR, AR, MR) classes to become available in the future, 2 were unsure, and only one did not expect that. From those who expected, some highlight that the use of XR technology "can help to create more engaging and immersive learning experiences, making these types of classes more appealing for both students and educators", can be "more convenient and fun", "would bring easier understanding" and "unavoidable technology shift", can be used "in the same class to explain and learn about various things that could not be so well in rudimentary classes", a participant believes "it is the next step from text to images, from images to videos, and from videos to 3D environments", and one reports that XR technology will be used, but not very soon ("Yes, but not in the near future." ... "Main reason is it's costly for both organizations and students, a cost NOT worth paying at the current state of these technologies."). See **Figures 22, 23**.

Finally, 63.2% of the student participants believe that the University/school will implement XR (AR, VR, MR) technologies within its curriculum by establishing a sustainable and suitable framework within the next 5 years (**Figure 24**).

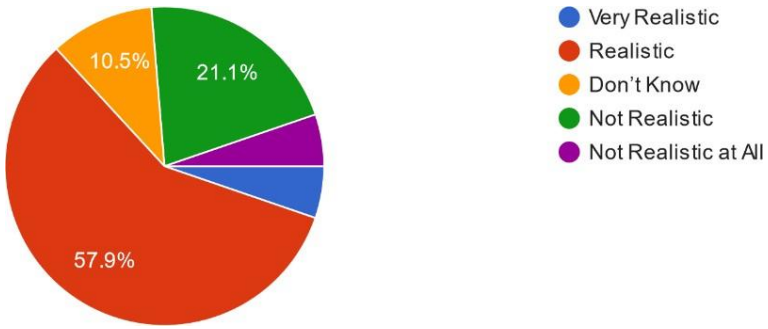

Figure 24: *Responses to In your opinion how realistic do you think it is that the University/school will implement XR (AR, VR, MR) technologies within its curriculum by establishing a sustainable and suitable framework within the next 5 years?*

15 Conclusion

15.1 Discussion

In conclusion, the survey conducted among the 48 experts revealed several key findings. Firstly, the gender distribution among the participants was imbalanced, with only 10 out of the 48 experts being female. Secondly, the age distribution of the sample was not specified in the given information. Regarding the experience with XR technology, the median duration of usage among the participants was 5 years, indicating a relatively substantial level of experience. However, the frequency of usage varied, with participants reporting XR technology usage as "Sometimes" on average.

The experts demonstrated a predominantly high level of self-perceived awareness of XR technology's current use for educational purposes. Participants rated themselves as "Aware" with a median score of 4 out of 5, indicating a strong awareness of the applications of XR in education. In terms of programming and designing new educational tools based on XR, the participants expressed a generally perceptive attitude, with a median rating of 4 out of 5. This suggests that the surveyed experts possess a considerable level of skill and proficiency in utilizing XR technologies for educational tool development.

The participants' knowledge about XR was slightly above average, with a median rating of 3.5 out of 5. This indicates a moderate level of understanding and familiarity with XR technology among the experts. Most of the experts did not have prior experience using XR technology to assist in education. However, a significant number of participants acknowledged the lack of sufficient training on the possible applications of XR at their respective universities.

The importance of XR's didactic usefulness in designing educational experiences was deemed high, as indicated by a median rating of 4 out of 5. Participants expressed a strong belief in the value of XR as a tool for enhancing educational experiences. While participants showed less concern for realism in XR experiences, both 3D design and immersion were considered important aspects, with a median rating of 4 out of 5 for each.

The experts expressed a high level of confidence, with a median rating of 4 out of 5, in the belief that XR can assist in various aspects of education. These aspects include knowledge transfer, workflow familiarization, procedural training, off-site content delivery, education of large student populations, and standardized knowledge assessment. Most experts indicated their intention to develop an XR teaching tool within their courses, demonstrating a proactive approach toward integrating XR into education. The perception of XR as a passing trend was divided among the experts, with some considering it as such while the majority did not. However, there was a shared belief in high acceptance of XR as a teaching resource.

Experts largely agreed that XR will likely become a standard tool in university environments for knowledge transmission. They also believed that offering XR content would influence how students perceive a

university's teaching environment, indicating the potential for XR to shape the perception of progressive and modern educational institutions. The surveyed sample of experts considerably agreed with the statement that XR is a powerful tool that should be used in teaching within educational environments. The major barriers identified for the implementation of XR technologies in schools and universities were cost/funding, technical concerns/technical know-how, and limited technology infrastructure. Conversely, the disruption to traditional learning was seen as a less significant barrier. These conclusions provide insights into the opinions, experiences, and beliefs of the surveyed experts regarding XR technology and its applications in education. The findings highlight the potential benefits of XR, the existing challenges, and the experts' overall positive attitude toward integrating XR into educational environments.

The survey findings revealed that among the student participants, a small percentage had already used XR technology in their school courses. However, the majority expressed a strong preference for courses that incorporate XR technology as a teaching tool, even if they were not particularly interested in the course content. Concerns were raised about accessibility, interaction, and potential distractions associated with XR in lectures.

Nonetheless, most students expected XR classes to become available in the future, highlighting the perceived benefits of immersive and engaging learning experiences. While cost-related challenges might delay widespread implementation, a significant proportion believed that their university or school would adopt XR technologies within the next five years. Overall, the findings demonstrated the students' growing interest in and positive attitude towards XR as a powerful tool for transforming education.

References

1. Meccawy, M. (2022). Creating an Immersive XR Learning Experience: A Roadmap for Educators. Electronics, 11(21), 3547
2. Vergara, D., Antón-Sancho, Á., Dávila, L. P., & Fernández-Arias, P. (2022). Virtual reality as a didactic resource from the perspective of engineering teachers. Computer Applications in Engineering Education, 30(4), 1086-1101
3. Dalager, S., & Majgaard, G. (2022, May). Development of an Educational AR Tool for Visualization of Spatial Figures and Volume Calculation for Vocational Education. In Virtual, Augmented and Mixed Reality: Applications in Education, Aviation and Industry: 14th International Conference, VAMR 2022, Held as Part of the 24th HCI International Conference, HCII 2022, Virtual Event, June 26–July 1, 2022, Proceedings, Part II (pp. 14-30). Cham: Springer International Publishing
4. Yang, K., Zhou, X., & Radu, I. (2020). XR-ed framework: Designing instruction-driven and Learner-centered extended reality systems for education. arXiv preprint arXiv:2010.13779
5. 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), 21582440221093348
6. Vygotsky, L. S. (1978). Mind in Society: The Development of Higher Psychological Processes. Harvard University Press. XR ASSOCIATION RELEASES ILLUSTRATIVE ON IMMERSIVE TECHNOLOGY, Harun & Bethany, https://xra.org/xr-association-releases-illustrative-on-immersive-technology/
7. Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Prentice-Hall
8. Gardner, H. E. (2000). Intelligence reframed: Multiple intelligences for the 21st century. Hachette UK.
9. Reeves, T. (2006). Design research from a technology perspective. In Educational design research (pp. 64-78). Routledge.
10. Basu, R. (2021). Instructional Design Models: Benefits and Challenges. 41. 31-36.
11. Bloom, B. (1956). Taxonomy of educational objectives. Handbook I: Cognitive domain. David McKay Co Inc. Puentedura, R. (2012). The SAMR Model: A Practical Guide for EdTech Integration. Retrieved from: https://www.commonsense.org/education/articles/the-samr-model-explained-for-teachers
12. Puentedura, R.R. (2006). SAMR: A model for technology integration. From https://hippasus.com/blog/archives/227.
13. CAST. (2018). Universal Design for Learning Guidelines version 2.2. Retrieved from http://udlguidelines.cast.org/
14. Afjar, A, Musri, & Syukri, M. (2020). Attention, relevance, confidence, satisfaction (ARCS) model on students' motivation and learning outcomes in learning physics. Journal of Physics: Conference Series. 1460. 012119. 10.1088/1742-6596/1460/1/012119.

15. Mishra P, Koehler MJ. (2006) Technological pedagogical content knowledge: A framework for teacher knowledge. Teachers College Record, 108(6), 1017-1054.
16. Arnab, S., Lim, T., et al. (2015). Mapping learning and game mechanics for serious games analysis. British Journal of Educational Technology, 46(2), 391-411.
17. Romero, M., Ouellet, H., Sawchuk, K. (2017). Expanding the Game Design Play and Experience Framework for Game-Based Lifelong Learning (GD-LLL-PE). In: Romero, M., Sawchuk, K., Blat, J., Sayago, S., Ouellet, H. (eds) Game-Based Learning Across the Lifespan. Advances in Game-Based Learning. Springer, Cham. https://doi.org/10.1007/978-3-319-41797-4_1
18. Fernandes, F. A., Rodrigues, C. S., Teixeira, E. N., & Werner, C. M. (2023). Immersive learning frameworks: A systematic literature review. *IEEE Transactions on Learning Technologies*, 16(5), 736–747. https://doi.org/10.1109/tlt.2023.3242553
19. Dengel, A., Iqbal, M. Z., Grafe, S., & Mangina, E. (2022). A review on augmented reality authoring toolkits for education. Front. Virtual Reality, 3
20. Ketelhut DJ, Dede C, Clarke J, Nelson B (2006) A multi-user virtual environment for building higher order inquiry skills in science. In: Annual conference of the American educational research association, San Francisco.
21. Ryoo, J., & Winkelmann, K. (2021). Innovative learning environments in STEM higher education: Opportunities, challenges, and looking forward.
22. Olasoji R, Henderson-Begg S (2010) Summative assessment in second life: a case study. J Virtual Worlds Res 3(3). https://doi.org/10.4101/jvwr.v3i3.1460.
23. Mislevy RJ, Haertel GD, Riconscente MM, Rutstein D, Ziker C (2017) Assessing model-based reasoning using evidence-centered design: a suite of research-based design patterns. Springer, New York. https://www.springer.com/us/book/9783319522456.
24. Baker RSJD, Clarke-Midura J (2013) Predicting successful inquiry learning in a virtual performance assessment for science. In: Carberry S, Weibelzahl S, Micarelli A, Semeraro G (eds) User modeling, adaptation, and personalization. UMAP 2013. Lecture notes in computer science, vol 7899. Springer, Berlin, Heidelberg.
25. Jiang Y, Paquette L, Baker R, Clarke-Midura J (2015) Comparing novice and experienced students in virtual performance assessments. In: Proceedings of the 8th International conference on educational data mining, Madrid, 26–29 June.
26. Rose H (1995) Assessing learning in VR: towards developing a paradigm virtual reality roving vehicles (VRRV) project. Human Interface Laboratory.
27. Salii, B. (2022). Using extended reality technology in education. Economics, Finance and Management Review, (2), 85–94. https://doi.org/10.36690/2674-5208-2022-2-85
28. Lee, J. J., & Hu-Au, E. (2021). E3XR: An analytical framework for ethical, educational and eudaimonic XR design. Frontiers in Virtual Reality, 2, 697667.
29. Abraham, M., Saeghe, P., Mcgill, M., & Khamis, M. (2022, October). Implications of XR on Privacy, Security and Behaviour: Insights from Experts. In Nordic Human-Computer Interaction Conference (pp. 1-12).

30. Garrido, G. M., Nair, V., & Song, D. (2023). SoK: Data Privacy in Virtual Reality. arXiv preprint arXiv:2301.05940.

Annex I: Questionnaires Experts

Section I (Information on the participant)

1) Country:

2) Sex:
   Male
   Female
   Other

3) Age:
   18-24 years old
   25-34 years old
   35-44 years old
   45-54 years old
   55-64 years old
   Over 65 years old

4) Employment status:
   Permanent
   Contract
   Temporary
   Unemployed
   Internship

5) Years of working experience:
   Less than 5 years
   6-10 years of experience
   11-15 years of experience
   16-20 years of experience

21-25 years of experience
More than 25 years of experience

6) Period of work experience with the XR (AR, VR, MR)

7) Are you currently a staff member of:
Elementary School
High School
College
Higher Education Institution
Vocational Institution
Other organization

8) Academic Level:
Graduate
Master
Ph.D.
Other (Please specify)

Section 2 (Exposure to XR (AR, VR, MR) technologies prior to the use as a teaching tool)

1) Do you have prior experience with XR (AR, VR, MR) technology, either through personal or professional experience? (Kluge, M. G., Maltby, 2022)
None
Once
A few Times
Regularly

2) How often do you use XR (AR, VR, MR) technology?
Very often
Often
Sometimes

Rarely

Never

3) Which technology platform are you most familiar with? (Kluge, M. G., Maltby, 2022)

4) How aware are you of the current use of XR (AR, VR, MR) technology for educational purposes? (Kluge, M. G., Maltby, 2022)

Very Aware

Aware

Neither

Not so aware

Unaware

5) Rate from 1 to 5 your self-perception of your digital skills to program or design new information and communication technologies-based educational tools

6) Rate from 1 to 5 your level of knowledge about XR (AR, VR, MR)

7) Do you feel that you have received sufficient training at your university on the possible applications of XR (AR, VR, MR) in education?

Section 3 (XR technology tool- metrics)

1) Have you used XR technology (either VR, AR or any other) to assist in education in any form? (Kluge, M. G., Maltby, 2022)

Yes

No

If yes, please specify

2) Rate from 1 to 5 your difficulty to navigate using Head Mounted Display? (Dalager, S., & Majgaard, G., 2022)

3) Rate from 1 to 5 your difficulty to navigate using Joystick? (Dalager, S., & Majgaard, G.,2022)

4) Have you used any other alternative medium or technology that you would consider non-standard to any of your teaching course? Which one? (Kluge, M. G., Maltby, 2022)

   Yes (Please specify)

   No

5) Rate from 1 to 5 the level of importance you give to the didactic usefulness of XR (AR, VR, MR) when designing an educational experience

6) Have you been directly involved in the development of content, used dST (Distributed Simulations Technology) in a course as a teaching tool or both? (Kluge, M. G., Maltby, 2022)

   Yes

   No

   Don't know

7) Please rate the level of importance of the following technical aspect of XR (AR, VR, MR) when designing an XR (AR, VR, MR) educational experience: Three-dimensional design

8) Please rate the level of importance of the following technical aspect of XR (AR, VR, MR) when designing an XR (AR, VR, MR) educational experience: Immersiveness

9) Please rate the level of importance of the following technical aspect of XR (AR, VR, MR) when designing a XR (AR, VR, MR) educational experience: Realism

10) Rate from 1 to 5 your opinion about the possibility of your educational institution implementing virtual reality in its teaching activities

11) Rate the level of inconvenience of the following aspects of XR (AR, VR, MR): Costs

12) Rate the level of inconvenience of the following aspects of XR (AR, VR, MR): Spatial limitations

13) Rate the level of inconvenience of the following aspects of XR (AR, VR, MR): Demand for technical and human resources

14) Rate the level of inconvenience of the following aspects of XR (AR, VR, MR): Requirement of specific knowledge of the part of teachers and technicians

15) Rate the level of inconvenience of the following aspects of XR (AR, VR, MR): Technological obsolescence

16) Rate from 1 to 5 the possible level of acceptance of XR (AR, VR, MR) as a teaching resource that you think your students have (or would have)

Section 4 (Development)

1) How confident are you that XR (AR, VR, MR) can in principle enable or assist with: (Kluge, M. G., Maltby, 2022)

	Extremely Confident	Considerably Confident	Moderately Confident	Slightly Confident	Not at all Confident
Factual Knowledge Transfer					
Workflow familiarization					
Procedural training of activities of high risk or high costs					
Flexible off site and remote delivery of content					
Effective education of a high number of students from different degrees					
Standardized delivery of knowledge to					

university/school students					
Standardised assessment of knowledge to university/school students					

2) Do you have any concerns about the use of XR (AR, VR, MR) within the university curriculum, excluding practical implementation and funding issues? (Kluge, M. G., Maltby, 2022)

3) Setting aside the issues of practical implementation, would you develop an XR (AR, VR, MR) teaching tool within your course, given an opportunity to do so? (Kluge, M. G., Maltby, 2022)

Yes

No

Don't Know

4) Value the importance of interaction when designing an educational experience with XR (AR, VR, MR)

5) Assess the importance of user experience when designing an educational experience with XR (AR, VR, MR)

6) Assess the importance of employability when designing a XR (AR, VR, MR) educational experience.

Section 5 (General Attitude)

1) To what extent do you agree with the following statements? (Kluge, M. G., Maltby (2022)

	Extremely	Considerably	Moderately	Slightly	Not at all
XR (AR, VR, MR) technology as a whole is a passing trend.					

XR (AR, VR, MR) are a powerful tool and should be used in teaching within educational environments.					
The use of XR (AR, VR, MR) in teaching is a distraction from the teaching content and learning objectives.					
Teaching and education have to continuously change and evolve.					

2) In your opinion, how likely is it that technologies XR (AR, VR, MR) will become a standard tool to facilitate transmission of knowledge within university environments (lab or lecture)? (Kluge, M. G., Maltby, 2022)

   Very likely

   Likely

   Somewhat likely

   Unlikely

   Very unlikely

3) How important do you believe the ongoing support of the technology is to the viability and usefulness of the technology? (Kluge, M. G., Maltby, 2022)

   Very important

   Important

   Neither

   Less important

   Not important

4) In your opinion, how likely is it that offering XR (AR, VR, MR) content will influence how current/future students think about university's ability to offer a progressive modern teaching environment? (Kluge, M. G., Maltby, 2022)

   Very likely

Likely

Somewhat likely

Unlikely

Very unlikely

5) Setting aside the issues of practical implementation, would you develop an XR (AR, VR, MR) teaching tool within your course, given an opportunity to do so? (Kluge, M. G., Maltby,2022)

Very likely

Likely

Somewhat likely

Unlikely

Very unlikely

6) In your opinion how realistic do you think it is that the universities/schools will implement XR (AR, VR, MR) technologies within their curriculum by establishing a sustainable and suitable framework within the next 5 years? (Kluge, M. G., Maltby, 2022)

Very Realistic

Realistic

Don't Know

Not Realistic

Not Realistic at All

7) Where do you see the biggest barriers for implementation of XR (AR, VR, MR) technologies within the next 5 years at the universities/schools? (Kluge, M. G., Maltby,2022)

Cost/Funding

Technical Concerns/ Technical know-how

Privacy and Ethical Issues

Disruption to Traditional Learning

Digital Literacy

Limited Technology Infrastructure

Accessibility

8) Do you believe that the use of XR (AR, VR, MR) in educational environments increases (or would increase) the academic performance of your students?

9) Do you believe that the use of XR (AR, VR, MR) in educational environments increases (or would increase) your students' motivation to learn?

10) Do you consider that the application of XR (AR, VR, MR) in educational environments helps (or would help) to improve the progress of your subject?

11) Rate from 1 to 5 the degree to which you think that the implementation of IXR (Immersive Extended Reality) will increase in the future at your university.

12) Rate from 1 to 5 the degree to which you think that the implementation of NIXR (Immersive Extended Reality) will increase in the future at your university.

Annex II: Questionnaire Students (above 18 years of age)

Introduction to Questionnaire

Extended reality (XR) refers to a category of immersive technologies that merge the physical and virtual worlds to create new environments where users can interact with digital content in more natural and intuitive ways. XR encompasses a range of technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR).

Virtual reality (VR) involves creating a fully immersive, computer-generated environment that users can experience through a headset or other specialized hardware. Users can interact with this environment through motion controllers or other input devices, and the experience can be highly realistic and immersive.

Augmented reality (AR) involves overlaying digital information onto the user's view of the physical world, typically using a smartphone or tablet camera. This technology can be used to enhance the user's understanding of a real-world environment or to create new, interactive experiences.
Mixed reality (MR) combines elements of both VR and AR.

Section I (Information on the participant)

1) Country:
2) Sex:
   Male
   Female
   Other
3) Age:
   18-24 years old
   25-34 years old
   35-44 years old
4) Education:
   High School
   Bachelor
   Masters
   Ph.D.
   Other (please specify)
5) Field of study (if in university):

Section 2 (Exposure to XR technologies prior to the use as a teaching tool)

8) Do you have prior experience with XR technology (AR, VR, MR)? (Kluge, M. G., Maltby, 2022)
   None
   Once
   A few Times
   Regularly

9) Which technology platform are you most familiar with? (Kluge, M. G., Maltby, 2022)

10) How long have you spent directly engaged with this/these technologies? For example, how long have you spent using an AR/VR/MR headset? (Kluge, M. G., Maltby, 2022)

11) Are you involved or have you been involved in course coordination and/or the development or content for university courses? (Kluge, M. G., Maltby, 2022)

Section 3 (XR technology tool- metrics)

1) Have you used XR technology (either VR, AR or any other) in any of your courses? (Kluge, M. G., Maltby, 2022)
   Yes
   No

2) Rate from 1 to 5 your difficulty to navigate using Head Mounted Display? (Dalager, S., & Majgaard, G., 2022)

3) Rate from 1 to 5 your difficulty to navigate using Joystick? (Dalager, S., & Majgaard, G., 2022)

4) What is your preferred movement in XR (VR, AR, MR): (Dalager, S., & Majgaard, G., 2022)
   Head Mounted Display/ Lean In
   Joystick
   Depends on the task

5) How difficult was your experience performing this experiment? (Dalager, S., & Majgaard, G., 2022)

6) Did you experience any form of dissiness or nausea while performing the tasks? (Please explain your answer) (Dalager, S., & Majgaard, G., 2022)

7) If so, what type of movement caused this? ((Dalager, S., & Majgaard, G., 2022)

8) Do you expect XR (VR, AR,MR) classes to become available in the future? (Please explain your answer) ((Dalager, S., & Majgaard, G., 2022)

9) Did you find any positive/negative experiences while doing the tasks? (Dalager, S., & Majgaard, G., 2022)

10) Any additional comments for improvement? (Dalager, S., & Majgaard, G., 2022)

Section 4 (General Attitude)

1) How would you like the XR (AR, VR, MR) technology to be made accessible to you for learning purposes? (Kluge, M. G., Maltby (2022)

2) Would you like to have the opportunity to rent or borrow hardware from the University/school to take home? (Kluge, M. G., Maltby, 2022)
   Yes
   No

3) How likely are you to buy or be gifted any form XR (AR, VR, MR) technology hardware (such as a VR/AR/MR headset) in the next 5 years? (Kluge, M. G., Maltby, 2022)
   Very Likely
   Likely
   Don't Know
   Not Likely
   Not Likely at All

4) Would your answer change, knowing that the University/school will be investing in new technologies and is likely to utilise XR (AR, VR, MR) technologies in the future? (Kluge, M. G., Maltby, 2022)
   Yes
   No

5) How likely are you to select a course that offers XR (AR, VR, MR) technology as a teaching tool over a similar course without? (Kluge, M. G., Maltby, 2022)
Very Likely
Likely
Don't Know
Not Likely
Not Likely at All

6) How likely are you to select a course that offers XR (AR, VR, MR) technology as a teaching tool even though you might not be overly interested in the course content as a whole? (Kluge, M. G., Maltby, 2022)
Very Likely
Likely
Don't Know
Not Likely
Not Likely at All

7) Do you have any concerns about the use of XR (AR, VR, MR) technologies within the university/school curriculum? (Kluge, M. G., Maltby, 2022)

8) In your opinion how realistic do you think it is that the University/school will implement XR (AR, VR, MR) technologies within its curriculum by establishing a sustainable and suitable framework within the next 5 years?
Very Realistic
Realistic
Don't Know
Not Realistic
Not Realistic at All