UNIVERSITA' CATTOLICA DEL SACRO CUORE DI MILANO

PhD Degree in Psychology

Cycle XXXVIII

S.S.D. M-PSI-01

Extending the Future of Learning:
Towards Immersive Experiences in Higher Education

PhD Candidate: Sabrina Bartolotta

Student ID number: 5214066

A.Y. 2024/2025

Table of Contents

Figures

Tables

Boxes

Acronyms

Acronym	**Full Form**
ABS	Absorption
AR	Augmented Reality

Acronym	**Full Form**
CAMIL	Cognitive-Affective Model of Immersive Learning
CAST	Center for Applied Special Technology
C.E.R.P.S.	Comitato Etico per la Ricerca in Psicologia
CLT	Cognitive Load Theory
CoI	Community of Inquiry
CTML	Cognitive Theory of Multimedia Learning
DBR	Design-Based Research
DICE	Dangerous, Impossible, Counterproductive, Expensive (Bailenson Framework)
DT	Design Thinking
EaT	Geographical Education to the Territory
ECM	Expectation-Confirmation Model
EECM	Extended Expectation-Confirmation Model
EDUCAUSE	Association for the Advancement of Higher Education through IT
EFF	(Perceived) Effort
GDPR	General Data Protection Regulation
GIS	Geographic Information Systems
HMD	Head-Mounted Display
IT	Information Technology
IVR	Immersive Virtual Reality
LMS	Learning Management System
ME	Mental Effort
MR	Mixed Reality
MTL	Motivation To Learn
NAE	Negative Activating Emotions
NASA-TLX	NASA Task Load Index

Acronym	**Full Form**
NDE	Negative Deactivating Emotions
n.s.	Not significant
OE	Overall Effort
OpenXR	Open XR Runtime Standard
OXREF	Open XR for Education Framework
PAE	Positive Activating Emotions
PE	Physical Effort
QA	Quality Assurance
R^2	Coefficient of Determination
SDT	Self-Determination Theory
STEM	Science, Technology, Engineering, and Mathematics
SUS	System Usability Scale
TAM	Technology Acceptance Model
UD	Universal Design
UDL	Universal Design for Learning
UK	United Kingdom
UTAUT	Unified Theory of Acceptance and Use of Technology
UX	User Experience
VR	Virtual Reality
VRS	Virtual Reality Social
WCAG	Web Content Accessibility Guidelines
XR	Extended Reality
α / ω	Cronbach's Alpha / McDonald's Omega

Declaration of Transparency and Use of Artificial Intelligence Tools for Research and Writing

This doctoral dissertation was conceived, developed, and written by the Author, who assumes full responsibility for the originality, accuracy, and integrity of its content.

During the research, writing, and revision phases, a limited and transparent use of Artificial Intelligence (AI) tools was made to support specific tasks. In particular:

- *Elicit*[1] (2025 version) was used at the early stages of the doctoral work as a research assistant to support initial brainstorming and the identification of relevant literature.
- *NotebookLM*[2] (Google, 2024 version) was employed as a grounded AI tool to organize, summarize, and cross-reference materials, notes, and academic papers during the preparation of the various chapters.
- *ChatGPT*[3] (OpenAI, GPT-5, 2025 version) was finally used for linguistic refinement, and, in some cases, for the generation of illustrative images; whenever image generation was involved, it is explicitly acknowledged in the corresponding figure/ table captions.

These tools were employed exclusively as cognitive and creative supports, never to generate novel research content, analyze empirical data, or produce theoretical interpretations. All generated outputs were critically reviewed, verified, and edited by the Author to ensure compliance with academic integrity and scholarly rigor.

The use of artificial intelligence is disclosed here in accordance with the American Psychological Association (APA, 2023[4]) and AIP Publishing (2023[5]) guidelines, which emphasize transparency in AI-assisted writing.

Furthermore, the author's methodological stance is informed by the principles expressed in Vinchon et al. (2023), a work to which the Author contributed both theoretically and in its drafting. This publication advocates for a responsible and reflective paradigm of human-AI co-creation, a vision that also guided the ethical and methodological integration of AI tools throughout the development of this dissertation.

[1] https://elicit.com/
[2] https://notebooklm.google/
[3] https://chatgpt.com/
[4] https://apastyle.apa.org/blog/cite-generative-ai-references?utm_source=chatgpt.com
[5] https://publishing.aip.org/resources/researchers/policies-and-ethics/authors/

Abstract

Recent advances in Extended Reality (XR) technologies offer potential for higher education by creating interactive and experiential learning environments that can enhance student engagement through critical thinking, problem-solving, and collaboration. However, the adoption of XR within educational settings faces significant challenges, including high costs, and issues with accessibility and inclusivity. The present thesis seeks to address these challenges by: (i) examining stakeholder expectations, (ii) developing and validating a new instructional model for immersive learning (i.e., MetaLab Model), (iii) assessing its impact on student engagement, and (iv) offering practical guidelines and co-design tools to support inclusive and scalable XR integration. By adopting a design-based research approach and design thinking methodologies, this thesis contributes with both theoretical insights and practical tools to advance the responsible implementation of XR in higher education.

Introduction

The Rise of XR Technologies in Higher Education

The classroom has always been a mirror of its time, a space able to reflect the cultural, social, and technological changes of society. Over the course of the 19th and 20th century, educational environments have gradually integrated tools and languages that reshaped how teaching unfolds. From chalkboards and chalk, symbols of transmissive, lecture-based education, we moved to overhead projectors, and eventually to personal computers and digital platforms. Each transition (*see* paragraph "1.1 XR in Higher Education: A Review of Current Research" for a more extensive analysis of the state of the art in XR education), has reshaped the way the classroom is inhabited, altering both the roles of teachers and learners as well as the dynamics of learning itself.

A current transition involves the adoption of three-dimensional, interactive, and immersive environments (Fig. 1), which create experiential settings that allow students to explore, perform tasks, and engage in collaborative knowledge construction.

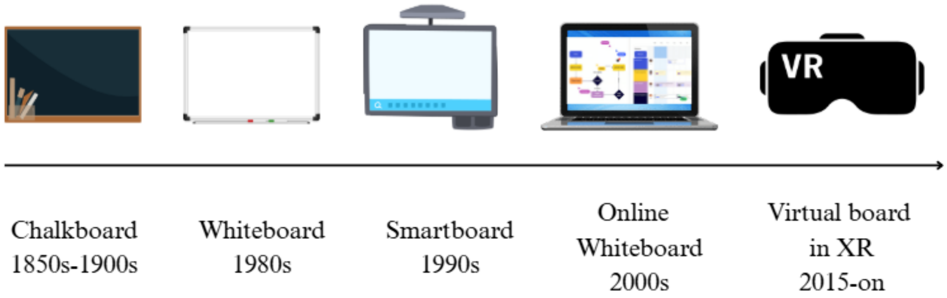
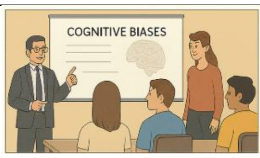


Fig. 1. Evolution of the educational board, from chalk to XR

This transition requires examining the psychological potential of these technologies and the characteristics of the environments in which learning occurs. The conceptual foundation of XR is most often traced back to the Virtuality–Reality (VR) Continuum proposed by Milgram and Kishino (1994). This model positions physical reality at one extreme and complete virtuality at the other, with Mixed Reality (MR) occupying the intermediate zone where real and virtual elements coexist and interact in real time. Within this framework, XR serves as an overarching term encompassing the full spectrum of mediated experiences that extend or replace physical perception through digital content. As we move along the VR Continuum, from Augmented Reality (AR), which overlays digital information onto the physical world, to fully immersive Virtual Reality (VR), which replaces sensory input with a simulated environment, the learner's experience becomes progressively more interactive, embodied, and immersive. The following examples (Tab. 1) illustrate how educational activities evolve along this spectrum, shifting from abstract and observational forms of learning toward experiential and participatory modes that engage cognitive, emotional, and sensorimotor dimensions.

Tab. 1. Four illustrative scenarios, each aligned with a different stage of the VR Continuum (Milgram & Kishino, 1994) from fully physical learning environments to completely virtual ones. AI-generated images created with ChatGPT [OpenAI, GPT-5, 2025 version].

	Real Environment	**Augmented Reality**	**Augmented Virtuality**	**Virtual Environment**
Narrative Example	The professor walks in the classroom, opens a PowerPoint, and begins a lecture on cognitive biases. Students sit in neat rows, listening and taking notes. A few raise their hands to ask questions about confirmation bias and heuristics. The discussion is lively but confined to verbal exchange and static images projected on a screen.	The Professor and students wear lightweight AR headsets. As the professor explains the limbic system, a glowing 3D model of a human brain appears floating above each desk. The physical classroom remains visible, but digital overlays bring abstract concepts to life.	Students log into a virtual learning platform. They appear as avatars in a richly designed 3D classroom. Some colleagues are logged in from home. A live-streamed video of their professor is projected onto a screen, allowing for real-time interaction. The classroom is fictional, but the voice and gestures of the teacher are real, maintaining social connection.	A group of psychology students has VR headsets and are instantly transported into a virtual mental health clinic. One student assumes the role of therapist; another becomes the observer. Inside the simulation, they interact with a virtual patient. They have to apply therapeutic techniques in real time. The experience is embodied and emotionally charged.
XR Elements	None	3D digital models overlaid on the real world	Mainly virtual world with live physical elements integrated	Fully computer-generated world and agents
Level of Immersion	None	Low to moderate	High	Maximum
Learning Mode	Traditional lecture format; verbal and visual learning	Visually enriched	Hybrid interaction	Experiential, high-fidelity simulation
Image				

Note. Augmented Reality is commonly defined as the overlay of digital information onto the real world without requiring precise spatial anchoring to physical objects, whereas Mixed Reality involves the placement of virtual content in a spatially contextualized and stable relationship with the physical environment. Although the experience described here, namely, the visualization of a three-dimensional brain model anchored on the student's desk, aligns more closely with Mixed Reality definitions, the broader term Augmented Reality is adopted for consistency with terminology widely used in educational contexts. A more detailed discussion of this conceptual distinction is provided in Paragraph 1.1.3.2.

Different configurations of XR technologies can shape the learner's experience along a continuum of immersion and interactivity. The shift from traditional environments to fully virtual simulations mark a transition not only into technological sophistication but in the psychological quality of the learning process itself, moving from passive reception to (possibly) active, embodied engagement. This conceptual progression is increasingly supported by empirical research. Recent literature underlines the potential of XR technologies in higher education, particularly for enhancing experiential learning, student engagement, and knowledge retention across a wide range of disciplines, from medicine and architecture to psychology and engineering (Idrees, Morton & Dabrowski, 2022; Fernández-Cerero et al., 2025; Fernández-Batanero & Montenegro-Rueda, 2025; Wang, Ma & Wei, 2023). XR environments allow for immersive, interactive simulations that support conceptual understanding, personalized learning, and active skill development, often outperforming or complementing traditional teaching methods (García-Robles et al., 2024; Curran et al., 2023).

Despite these promising outcomes, however, the adoption of XR remains largely limited to pilot projects and research initiatives, with few institutions embedding it at scale within mainstream curricula (Guilbaud, Guilbaud & Jennings, 2021; Crogman et al., 2025). Several barriers hinder its broader implementation: high production and infrastructure costs, the lack of validated instructional models, limited technological competencies among faculty, and ongoing concerns around accessibility and inclusivity (Idrees, Morton & Dabrowski, 2022; Kuleto et al., 2021). While some disciplines, such as medical education, have made significant strides (Radianti et al., 2020; Moro et al., 2021), these efforts are often domain-specific and do not offer generalizable frameworks that educators can adopt autonomously. In fact, much of the existing literature is fragmented, focusing on isolated case studies or narrowly defines technological solutions (Parong & Mayer, 2021), rather than presenting a cohesive, actionable strategy for the design and implementation of XR-based learning experiences. This limits both scalability and the democratization of XR integration in education. Many educators report a lack of institutional guidance and support in integrating XR into their teaching practices, revealing an urgent need for strategic frameworks, training programs, and interdisciplinary collaboration (Idrees, Morton & Dabrowski, 2022; Wang et al., 2023). While students, particularly from Generation Z, increasingly value XR as a flexible and empowering tool, its long-term educational impact and optimal modes of integration remain underexplored, calling for further empirical research and systemic investment (Kuleto et al., 2021; Curran et al., 2023).

The present Thesis seeks to address some of these challenges. More specifically, it aims at: (i) understanding the expectations and concerns of students and faculty members regarding XR in higher education; (ii) designing and developing an instructional model for immersive learning, the "MetaLab" framework; (iii) evaluating the impact of the MetaLab-based learning experiences on students' cognitive, social, and emotional engagement; (iv) provide practical guidelines and co-design tools for educators and instructional designers to support inclusive and scalable implementation of XR-based learning interventions.

The following introductory paragraphs outline the methodology adopted throughout the three-year PhD research, followed by an overview of the Metaversity project, an institutional initiative within which this doctoral research is situated, and its implementation timeline. Together, the following paragraphs provide an outline of how the present work objectives have been operationalized in practice and how research evidence was generated to advance research on XR-based learning in higher education.

Methodological approach

The next sections introduce Design-Based Research (DBR) and Design Thinking (DT) frameworks and explain how the methodology of the present doctoral work has been informed. With the term DBR we refer to a programmatic approach[6] to studying and improving the research process in naturalistic settings through iterative cycles (e.g., Analysis → Design → Development → Implementation → Evaluation; Kurt, 2017) conducted in close collaboration with practitioners. The aim of this approach is two-fold: (i) to produce locally effective interventions and (ii) to generate transferable design principles or mid-range theory (Brown, 1992; Design-Based Research Collective, 2003; Barab & Squire, 2016; Wang & Hannafin, 2005). Complementarily, DT is a human-centered, solution-focused methodology that integrates empathy work, problem framing, creative ideation, rapid prototyping, and evidence-informed testing to navigate uncertainty and align solutions with user needs and organizational constraints, thereby supporting more rigorous and reflective decision-making in the research process (Brown, 2008; Razzouk & Shute, 2012; Liedtka, 2018).

DBR seeks to produce knowledge that is both theoretically informed and practically applicable. Although different approaches to DBR have been proposed (Design-Based Research Collective, 2003), they generally share the use of iterative cycles of analysis, such as those outlined in the ADDIE model (Kurt, 2017), to develop usable theory (e.g., design principles, explanatory models) while concurrently refining interventions within real-world contexts (Brown, 1992; Collins, 1992; Design-Based Research Collective, 2003; Barab & Squire, 2016). DBR frameworks emphasize the specification of objectives, deliverables, and outputs at each stage of the process, underlining the importance of feasibility studies, pilot testing, and scaling procedures as strategies to support cumulative knowledge building (Cobb et al., 2003; McKenney & Reeves, 2018). In addition, DBR is conducted in situ, for example, in courses, laboratories, or curricula, thereby enhancing ecological validity and ensuring consistency with authentic contextual constraints such as time, technological resources, and institutional policies (Wang & Hannafin, 2005; Anderson & Shattuck, 2012). For a more detailed description of this approach, *see* the following section on “Design-Based Research: the ADDIE Model.”

DT introduces a human-centered process that supports both the framing of problems and the development of solutions. Similar to other iterative methodologies, DT is often structured in cycles such as Empathize → Define → Ideate → Prototype → Test. A distinctive feature of this approach is the initial empathy phase, which relies on methods such as interviews, observations, and experiential workshops to investigate stakeholders’ needs, expectations, goals, and tacit practices, and to translate these into design requirements (Brown, 2008; Liedtka, 2018). This emphasis reduces the likelihood of adopting solutionist approaches and contributes to more precise problem framing. DT also employs divergent–convergent cycles, which broaden the range of possible alternatives and subsequently narrow them by applying explicit decision criteria. This process facilitates evidence-based decisions about what is desirable, feasible, and viable (Beckman & Barry, 2007; Razzouk & Shute, 2012). In this respect, user insights and contextual evidence are progressively refined

[6] A coherent, sequenced program of studies/interventions anchored in one theoretical framework and aimed at cumulative objectives.

into shortlists of viable solutions (Beckman & Barry, 2007; Liedtka, 2018). Most DT models also include a prototyping phase between ideation and testing to strengthen the divergent–convergent rhythm: low-fidelity prototypes allow teams to externalize multiple alternatives at low cost, then to evaluate them through user feedback and explicit criteria of desirability, feasibility, and viability (Beckman & Barry, 2007; Brown, 2008; Razzouk & Shute, 2012; Liedtka, 2018). Prototypes function as epistemic artifacts, transforming empathy-based insights into testable hypotheses, making underlying assumptions explicit, and reducing uncertainty through iterative cycles of creation, testing, and refinement (Dorst, 2011).

In the present work, DBR and DT have been operationalized through the ADDIE model (Kurt, 2017; Widyastuti, 2019) and the Stanford d.school (2010) design-thinking framework, respectively, since together they provide a pragmatic balance between procedural rigor and human-centered agility, well suited to the design, implementation, and assessment of XR interventions in higher education (Parker, 2011; Herrington & Reeves, 2011; Wood & Bilsborow, 2014; Greenbaum et al., 2025). The subsequent sections delineate the two frameworks.

Design-Based Research: the ADDIE Model

Contrary to traditional experimental approaches that isolate variables under strictly controlled conditions, DBR (Box 1) acknowledges and leverages the complexity inherent in real-world educational contexts. Grounded in iterative design, DBR represents both a methodological approach to designing educational interventions and a means of rigorously studying their efficacy through cycles comprising analysis, design, implementation, reflection, and refinement (Reeves, 2006). This iterative and reflective nature allows to produce robust, contextually relevant theories and adaptable, scalable educational solutions.

BOX 1. Design-Based Research: Origins and Dimensions

Design-Based Research (DBR) emerged in the early 1990s as a response to the growing need for research methods capable of capturing the complexity of real-world learning environments. proposed by Brown (1992) and Collins (1992), DBR was designed to overcome the rigidity of laboratory experiments by studying innovation directly in authentic contexts. it integrates theory and practice through iterative cycles of design, implementation, analysis, and redesign. Its key dimensions include: (i) an interventionist approach, aimed at developing and testing educational innovations; (ii) an iterative process, where solutions evolve through successive refinements; (iii) a collaborative structure, engaging researchers and practitioners; and (iv) theoretical generalization, producing design principles that inform broader pedagogical understanding.

DBR is often integrated with established instructional design frameworks, such as the ADDIE model (Fig. 2), which is structured around five interconnected phases: Analysis, Design, Development, Implementation, and Evaluation (Kurt, 2017; Muruganantham, 2015). In the Analysis phase, learners' backgrounds, skills, and educational needs are examined to define instructional objectives and inform suitable pedagogical strategies. The Design phase focuses on planning learning objectives, instructional content, assessment methods, media selection, and activities, ensuring coherence and alignment with identified goals. During Development, the planned design is translated into concrete materials and activities, which are tested for effectiveness and adjusted as necessary. Implementation refers to the delivery of the educational intervention to learners, incorporating continuous feedback and ongoing adjustments to refine both materials and strategies. Evaluation takes place throughout the process (formative evaluation) as well as after its completion (summative evaluation), assessing the achievement of instructional goals, the overall effectiveness of the intervention, and areas requiring improvement. The iterative nature of the ADDIE model, with its continuous feedback loops, enhances flexibility and applicability, making it particularly suitable for supporting DBR's emphasis on practical and scalable educational innovation (Kurt, 2017; Beahm & Bradshaw, 2023; Widyastuti, 2019).

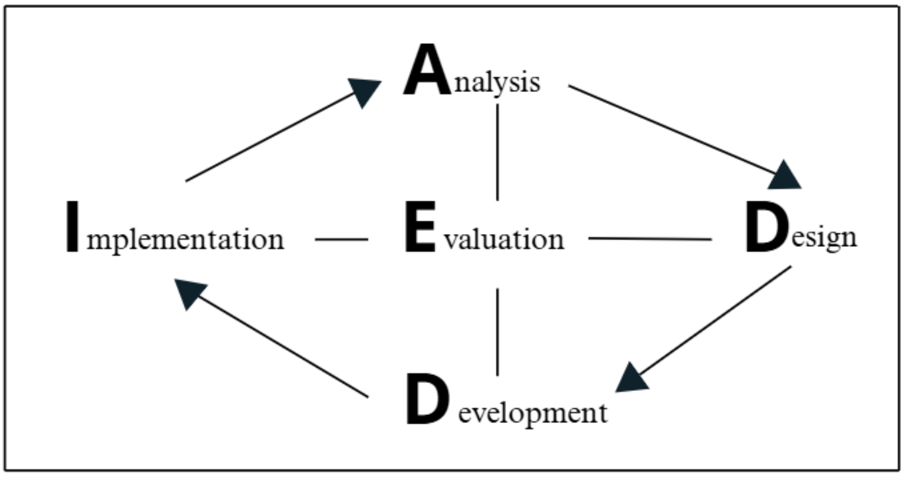


Fig. 2. The ADDIE Model (adapted from Kurt, 2017) represented as an iterative cycle composed of five distinct but interconnected phases (i.e., Analysis, Design, Development, Implementation, Evaluation) used to guide instructional design processes. Each phase systematically contributes to the continuous development and refinement of educational interventions.

The versatility of DBR in higher education has been documented across multiple disciplines and contexts. Singh (2009), for example, applied a hybrid DBR–ADDIE approach to design a web-based module for teaching metacognitive strategies. Iterative refinements based on qualitative feedback collected through interviews and questionnaires not only improved the intervention but also informed the enhancement of the traditional ADDIE framework. Similarly, Ustun and Tracey (2021) employed DBR with successive mixed methods cycles to redesign a blended psychology course, integrating validated surveys with expert and learner feedback to increase both educator satisfaction and student engagement. Wang (2020) implemented DBR over three phases to integrate interactive technologies, such as Google tools and student response systems, into undergraduate teaching. Peer assessments and direct student feedback indicated gains in retention and collaborative learning. In communication studies, Wood and Bilsborow (2014) developed a Creative Problem Solving (CPS) framework for first-year students through iterative cycles of design, testing, and implementation, resulting in both validated online tools and practical pedagogical guidelines.

Other applications illustrate DBR's capacity to address diverse needs and contexts. Jonsson (2017) employed Reeves' four-phase model to create digital interviewing techniques for special training, with stakeholder co-design emerging as a critical success factor. Karsten and van Zyl (2022) emphasized issues of equity and access by involving disadvantaged students in co-designing a first-year accounting intervention at a South African university, ensuring contextual relevance and ethical sensitivity. At a broader scale, Ford et al.

(2017) extended DBR into a Design-Based Implementation Research (DBIR) framework to test adaptive learning software in a large undergraduate accounting course in the United States. Across five iterative cycles, combined with a randomized controlled trial, they demonstrated improvements in student performance and validated the adaptive system.

Collectively, these studies illustrate DBR's adaptability, its attention to context-specific constraints, and its capacity to balance theoretical development with practical application. Common enabling factors include iterative refinement, mixed-method validation, stakeholder involvement, and attention to scalability and sustainability. At the same time, challenges such as limited time, ethical considerations, and inconsistent reporting practices highlight the importance of careful, transparent implementation to maximize the effectiveness of DBR.

Design Thinking: From Origins to the "d. school 2010" Model

While research increasingly adopts methodologies such as DBR, *Design Thinking* (Box 2) is also gaining growing attention as a methodological paradigm. The concept of DT has undergone a profound evolution from its early philosophical and cognitive foundations to its contemporary status as a multidisciplinary framework for innovation and problem-solving.

BOX 2. Design Thinking: Historical Genesis and Rationale

Design Thinking (DT) emerged as a response to the growing complexity of social, technological, and organizational challenges that could no longer be solved through purely analytical or linear methods. Rooted in the work of Herbert Simon (1969) and Donald Schön (1983), DT reframed design as a reflective and creative mode of inquiry that integrates intuition, experimentation, and analysis to address *wicked problems* (Rittel & Webber, 1973). During the 1990s, design consultancies such as IDEO and academic institutions like Stanford's d.school began to formalize DT into a structured process that could be applied beyond traditional design fields. Its rise reflected a cultural and methodological shift toward human-centered innovation, emphasizing empathy, collaboration, and iterative prototyping. In this sense, DT was conceived not only as a method for developing products or services, but as a mindset for navigating uncertainty, fostering creativity, and driving transformative change across disciplines.

Historically, DT emerged from the recognition that traditional scientific and engineering paradigms were insufficient to address complex, ill-structured, or "wicked" problems, those characterized by ambiguity, uncertainty, and interdependent variables (Rittel & Webber, 1973). In this sense, DT developed not merely as a set of creative techniques, but as an epistemological shift toward understanding design as a distinctive mode of inquiry and reasoning (Cross, 2001). The intellectual genealogy of DT can be traced back to the mid-twentieth century, when scholars such as Herbert Simon (1969) reframed design as a *science of the artificial*. Unlike the natural sciences, which seek to understand and explain the nature of existing phenomena, Simon (1969) proposed that design focuses on envisioning and creating what *ought to exist*, transforming current conditions into improved or desired futures. This insight marked the beginning of design's epistemological independence and introduced a new model of rationality, centered on synthesis, iteration, and adaptation rather than *deduction or induction*[7]. Simon's notion of "satisficing" solutions, those that are viable and contextually appropriate rather than optimal in a purely analytical sense, anticipated the iterative and pragmatic ethos of contemporary DT.

During the 1970s and 1980s, this foundational perspective was further developed by Donald Schön (1983), whose concept of the *reflective practitioner* emphasized the tacit, experiential, and situated nature of professional problem-solving. Schön described design as a process of *reflection-in-action*, in which practitioners engage in a dynamic dialogue with materials, contexts, and stakeholders, continuously reframing problems and testing hypotheses through action. This approach challenged positivist assumptions about knowledge production and placed emphasis on practice-based reasoning and experiential learning, key principles that would later underpin DT's iterative and human-centered processes.

Parallel to these theoretical developments, scholars such as Nigel Cross (1982, 2001) and Bryan Lawson (1980) contributed to the definition of a *designerly way of knowing*, recognizing design as a third mode of inquiry distinct from the sciences and the humanities. Cross's empirical studies on designers' cognitive processes highlighted *abductive reasoning*, the creative generation of plausible explanations or solutions, as central to design cognition. Unlike deduction (reasoning from general rules) or induction (reasoning from observed data), abduction allows the designer to imagine *what might be*, forming the epistemological foundation for DT's focus on possibility and innovation. Lawson's early studies comparing architects and scientists (1980) demonstrated how designers work through iterative cycles of divergence and convergence, exploring multiple problem framings before arriving at an integrated solution.

By the late 1980s, the academic discourse around design methods began to intersect with emerging movements in organizational innovation and human-centered design. Richard Buchanan (1992) notably defined DT as a *liberal art of technological culture*, capable of addressing problems of communication, interaction, and systems in a rapidly changing world. Buchanan's four "orders of design" (i.e., signs, things, actions, and environments) expanded the scope of design beyond products to include services, organizations, and social systems, laying the groundwork for its integration into business and education. Around the same time, Peter Rowe's *Design Thinking* (1987) provided one of the earliest explicit uses of the term, describing the reasoning processes of architects and planners as iterative, intuitive, and context dependent.

The consolidation of Design Thinking as a methodology occurred in the 1990s and early 2000s, particularly through the influence of the *Stanford University d.school* and the *Hasso Plattner Institute* (HPI) in Potsdam. Under the guidance of Larry Leifer, Christoph Meinel, and Hasso Plattner, DT was formalized into an educational and research framework characterized by human-centeredness, interdisciplinary collaboration, and iterative prototyping (Meinel, Leifer & Plattner, 2011; Meinel et al., 2020). These institutions provided an academic foundation for what had been largely a practitioner-driven movement,

[7] *Deductive reasoning* refers to a top-down logical process in which conclusions are derived from general premises or established theories; if the premises are true, the conclusion necessarily follows. *Inductive reasoning*, by contrast, follows a bottom-up logic that infers general principles or patterns from specific observations, yielding conclusions that are probable rather than certain. In the philosophy of science, these two modes of inference have traditionally defined the structure of scientific inquiry (Hempel, 1965; Popper, 1959). However, within design studies, they are often complemented by *abduction* a third form of reasoning oriented toward possibility and innovation rather than verification (Cross, 2006; Dorst, 2011).

integrating insights from cognitive science, management, and engineering. The HPI-Stanford Design Thinking Research Program (established in 2008) sought to empirically investigate the cognitive, social, and technological mechanisms underpinning creative collaboration, framing Design Thinking as both a research subject and an applied methodology.

Concurrently, the design consultancy IDEO and its CEO Tim Brown (2008) popularized DT within the business and innovation sectors. Brown's definition of Design Thinking as a human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success, encapsulated the model's pragmatic orientation. This reframing brought design practices, such as empathy mapping, brainstorming, and rapid prototyping, into the strategic and managerial domains of organizations, transforming design from a downstream aesthetic function into an upstream driver of innovation and strategy.

Robert Curedale's "Design Thinking: Process and Methods Manual" (2013) further systematized these practices into accessible models, identifying recurring stages (i.e., empathize, define, ideate, prototype, and test) across diverse industries. His work highlighted how Design Thinking had evolved from a designer's cognitive process into a shared language for interdisciplinary collaboration and problem reframing. In the same period, the method found fertile ground in education, where it became a pedagogical approach fostering creativity, agency, and experiential learning. Initiatives at Stanford's d.school, the HPI School of Design Thinking, and related programs in Europe and Asia demonstrated how Design Thinking could train students and professionals to approach complex social and technological challenges through empathy, experimentation, and co-creation.

In its contemporary form, DT represents the convergence of these multiple intellectual and practical trajectories. It integrates insights from systems thinking, cognitive psychology, participatory design, and innovation management, maintaining its commitment to human-centeredness while adapting to diverse contexts such as digital transformation, sustainability, and social innovation. Scholars such as Dorst (2011) and Liedtka (2015) emphasized that its enduring relevance lies not in a rigid process model, but in its *logic of abductive reasoning* and its ability to navigate uncertainty through iterative cycles of exploration and reflection.

Building on these theoretical foundations, the practical articulation of DT has taken shape through a variety of process models and methodological frameworks. These frameworks reflect different interpretations of the same underlying principles, empathy, iteration, and reflection, translated into structured approaches for guiding design practice. Brown (2008) outlines a non-linear structure composed of three overlapping phases (i.e., Inspiration, Ideation, and Implementation) each involving iterative sub-processes and opportunities for reflection. Gestwicki and McNely (2012), focusing specifically on educational design, propose a five-step sequence culminating in an "evolution" phase, which highlights iteration and refinement after initial implementation.

Among the various proposals, the five-phase model developed at the already mentioned Hasso Plattner Institute of Design at Stanford (d.school, 2010) has become the most widely adopted. This framework comprises the stages of Empathize, Define, Ideate, Prototype, and Test (Fig. 3), guiding teams through processes of user understanding, problem framing, idea generation, and iterative refinement through testing. Although often presented in a linear format for clarity, the model is inherently iterative and flexible, allowing movement across phases as new information and insights emerge (Meinel, Leifer, & Plattner, 2011).

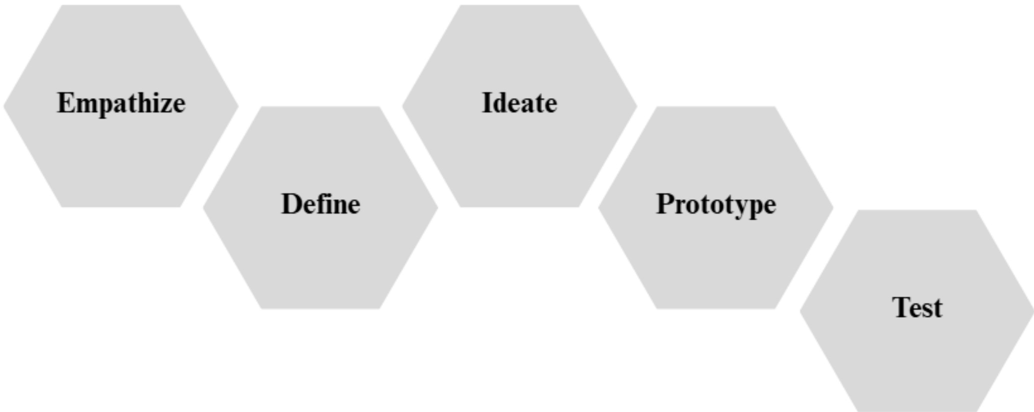


Fig. 3. The five-phase model of design thinking developed by the Hasso Plattner Institute of Design at Stanford (d.school, 2010). The model includes the phases of Empathize, Define, Ideate, Prototype, and Test.

Empirical studies highlight the potential of design thinking to generate effective and contextually relevant outcomes. Altman et al. (2018) and Nielsen, Christensen & Storvang (2021) observed improvements in usability, user satisfaction, and a stronger sense of strategic ownership, suggesting that design thinking, when applied as an iterative and user-centered methodology, can enhance both the quality and the creativity of design processes. Evidence from educational contexts further supports these findings. Darmawan et al. (2022) reported that combining systematic inquiry with iterative prototyping improved the quality of design outputs and increased user satisfaction. Likewise, Ulibarri et al. (2014) found that integrating design thinking into doctoral research contributed to the development of creative confidence and a more reflective understanding of the research process among students. Collectively, these studies indicate that design thinking not only facilitates innovation and user alignment but also promotes adaptive and reflective practices in research and learning.

The Interdependence of Test and Evaluation Phases in Iterative Design

In DBR and DT research frameworks, *Test* and *Evaluation* are not distinct or sequential steps, but rather mutually reinforcing processes that occur in parallel. Both aim to understand how a designed intervention performs in authentic contexts, yet they do so from complementary perspectives: *testing* focuses on the implementation and real-world enactment of the design, while *evaluation* focuses on the analysis and interpretation of its outcomes, effectiveness, and experiential qualities.

In the DBR tradition, this interdependence is intrinsic to the methodology itself. DBR cycles intentionally blur the boundaries between implementation and assessment, emphasizing that evaluation must be embedded within the process of testing rather than postponed until after it. As Reeves (2006) and McKenney and Reeves (2018) explain, implementation and evaluation together constitute the *empirical phase* of DBR, in which interventions are enacted in real educational settings and iteratively refined based on continuous feedback. Evaluation thus becomes both *formative* (i.e., informing ongoing redesign), and *summative*, (i.e., assessing the effectiveness of the intervention in achieving its learning goals). This dual function enables DBR to generate locally effective solutions and theoretically transferable design principles (Brown, 1992; Barab & Squire, 2016; Anderson & Shattuck, 2012).

In the ADDIE instructional design framework, *implementation* and *evaluation* are best understood as complementary and interdependent processes rather than strictly sequential stages. Implementation concerns the actual delivery of the designed learning intervention, bringing materials, technologies, and pedagogical strategies into real classrooms or training settings. However, evaluation is not a separate, subsequent phase; rather, it is embedded throughout implementation as a continuous mechanism for collecting, interpreting, and acting upon evidence regarding learning effectiveness, usability, and engagement.

As emphasized by Tessmer (1993) and later by McKenney and Reeves (2018), evaluation in ADDIE unfolds through two interrelated modes: *formative* and *summative*. Formative evaluation occurs *during* implementation and aims to support ongoing refinement. It involves activities such as classroom observations, usability testing, learner feedback sessions, and brief reflection interviews that help designers and instructors identify usability issues, instructional misalignments, or cognitive overload in real time. For instance, in Singh's (2009) hybrid DBR–ADDIE study on a web-based metacognitive training module, continuous learner feedback during implementation led to successive refinements in the learning interface and instructional sequencing, resulting in both improved learner engagement and theoretical insights into metacognitive scaffolding.

Summative evaluation, by contrast, is conducted *after* implementation and focuses on assessing the intervention's broader outcomes, its impact on learning, satisfaction, transferability, and potential for scaling (Gustafson & Branch, 2002; Beahm & Bradshaw, 2023). Yet, as Reeves (2006) observes, the two forms of evaluation are not discrete; summative conclusions often emerge cumulatively from iterative formative insights gathered during implementation. This continuity transforms the traditional linear ADDIE cycle into a reflective loop, in which implementation produces the empirical context for evaluation, and evaluation, in turn, informs further implementation cycles.

Empirical research in instructional design consistently illustrates this bidirectional relationship. In their redesign of a blended psychology course, Ustun and Tracey (2021) integrated formative and summative evaluation within implementation cycles, collecting both quantitative usability data and qualitative student reflections to guide iterative improvements. Similarly, Wang (2020) embedded evaluation instruments, such as peer reviews and learner self-assessments, within the implementation of interactive technologies in undergraduate teaching, demonstrating that continuous evaluation enhances instructional adaptability and learner engagement. These studies show that implementation and evaluation, when intertwined, create a form of *adaptive fidelity* (Reigeluth & Frick, 1999), where educational designs remain faithful to theoretical principles but flexible enough to respond to contextual dynamics and user feedback.

In this sense, implementation and evaluation operate as two sides of the same reflective process: implementation provides the lived context through which the design is enacted and experienced, while evaluation transforms those experiences into actionable knowledge. This dynamic interaction ensures that empirical data are not collected merely for post-hoc validation but serve as the foundation for evidence-informed iteration, enabling both the refinement of design practice and the development of mid-range educational theory (Brown, 1992; Barab & Squire, 2016). Within the present doctoral project, this integration is operationalized through the Test and Evaluation phase, where the implementation of the MetaLabs and their systematic assessment were conceived as a unified, cyclical process that simultaneously tested, refined, and validated the MetaLab framework in authentic university contexts.

Within instructional design research, similar reasoning is reflected in models such as ADDIE, where "Implementation" and "Evaluation" are conceptually distinct but operationally intertwined. Kurt (2017) notes that evaluation takes place continuously throughout the implementation phase, not only as a post-hoc activity. Formative assessments, usability tests, and learner feedback collected during the delivery of an instructional module constitute immediate data for improvement, while summative evaluations provide cumulative evidence for broader generalization and scaling (Beahm & Bradshaw, 2023; Widyastuti, 2019). In other words, testing without evaluation risks becoming anecdotal, while evaluation without testing lacks ecological validity, hence their methodological inseparability.

The same logic is echoed in Design Thinking. In the *Test* phase of the Stanford d.school model, testing is explicitly described as a learning opportunity rather than a final judgment (d.school, 2010; Brown, 2008). As Liedtka (2018) emphasizes, testing and evaluation together enable teams to validate hypotheses, surface unexpected user reactions, and refine both problem framing and solution quality. This is achieved through cycles of *build–measure–learn* (Ries, 2011) that merge prototyping, data collection, and reflection into a single continuous process. Here, evaluation is not limited to quantitative measurement but extends to the interpretive analysis of user experience, enabling designers and researchers to iterate based on evidence grounded in empathy and context (Dorst, 2011).

Empirical research confirms the effectiveness of integrating testing and evaluation as overlapping processes. For instance, Ustun and Tracey (2021) used successive mixed methods cycles to redesign a blended psychology course through DBR, collecting both quantitative usability data and qualitative feedback during each testing session. This allowed for real-time adjustments that increased engagement and satisfaction. Similarly, Wang (2020) demonstrated how embedding evaluation within testing cycles improved the integration of interactive technologies in undergraduate teaching, leading to sustained improvements across iterations. In the field of educational technology, Ford et al. (2017) extended this principle in a Design-Based Implementation Research (DBIR) framework, using five iterative test–evaluate cycles combined with randomized trials to validate adaptive learning software, thus demonstrating that continuous evaluation amplifies both the robustness and the scalability of results.

Taken together, these studies illustrate that testing and evaluation operate as a single reflective system. Testing provides the empirical ground for data collection, while evaluation transforms that data into actionable knowledge. Their integration ensures that design decisions remain responsive to user feedback and contextual dynamics, enabling cumulative knowledge building (Cobb et al., 2003) and enhancing both the ecological validity and the theoretical generalizability of findings.

Within the present doctoral project, this conceptual and methodological overlap is explicitly recognized. The Test and Evaluation phase was therefore conceived as a single, integrated process encompassing the delivery of MetaLabs and the systematic assessment of their outcomes. The decision to treat these two dimensions as interdependent aligns with DBR's cyclical structure and DT's reflective ethos, ensuring that the empirical testing of MetaLabs during the 2024–2025 academic year not only validated the framework's educational effectiveness but also informed its ongoing refinement through evidence-based iteration.

Doctoral Thesis Research Process

The theoretical frameworks and empirical contributions outlined above provided the foundation for structuring the methodological trajectory of this doctoral research across its three-year duration. Building on the structured yet adaptable features of the ADDIE model and the iterative principles of design thinking, the study adopted a four-phase process (i.e., Empathize, Prototype, Test, and Evaluate). Fig. 4 illustrates this iterative cycle, where the four phases are interconnected and continuously repeated to align design decisions with pedagogical objectives, contextual constraints, and user feedback.

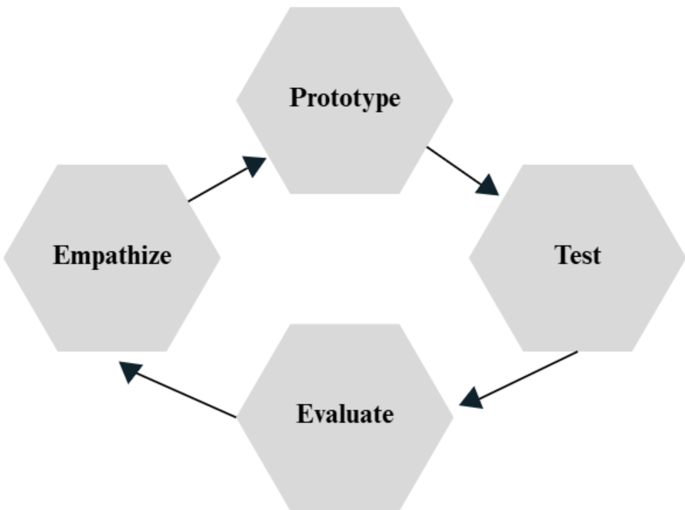


Fig. 4. Iterative design process adopted in this doctoral research, informed by DBR and design thinking principles. The model includes four interconnected phases: Empathize, Prototype, Test, and Evaluate, which are continuously repeated to refine XR-based educational interventions through user feedback, contextual understanding, and empirical validation.

This methodological framework reflects the adaptive and collaborative ethos of DBR, supporting the dual aim of generating actionable design principles and contributing to theoretical advancement. By embedding the research process within authentic educational environments, the study sought to ensure both ecological validity and practical relevance, allowing evidence-based applications and theory-in-use to emerge over time (Parker, 2011; Herrington & Reeves, 2011; Wood & Bilsborow, 2014; Turucz et al., 2021). The research is further contextualized within the broader Metaversity initiative, which is introduced in the following section.

The Metaversity Project

As previously described in the introduction, this doctoral thesis aims to contribute to the psychological research field related to XR learning by: (i) understanding the expectations and concerns of students and faculty members regarding XR in higher education; (ii) developing and testing a pedagogically grounded model for immersive learning, the MetaLab framework; (iii) evaluating the impact of immersive experiences on students' cognitive, social, and emotional engagement; and (iv) providing practical guidelines and co-design tools for educators and instructional designers to support inclusive and scalable implementation of XR-based learning interventions.

The present work is inscribed in, and contributes to, a broader research and development project called "Metaversity", an initiative internally funded by the Università Cattolica del Sacro Cuore from 2022 to 2025, which brings together faculty members and researchers from multiple faculties and departments to build research evidence related to XR learning in higher education. Fig. 5 shows an overview of the timeline related to Metaversity project and, congruently, the doctoral research progression.

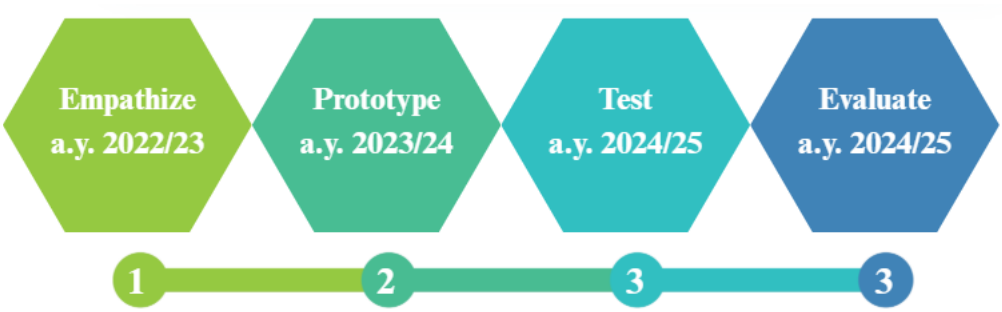


Fig. 5. Chronological overview of the Metaversity project and the doctoral work.

The *Empathize* phase (presented in Chapter 1) aimed to investigate the needs, expectations, and perceptions of key stakeholders, namely, faculty members and university students, regarding the use of XR technologies in higher education. Its objective was to identify both the pedagogical opportunities and the practical barriers associated with XR integration, thus providing an evidence base for the subsequent design phases. To achieve this, participatory and experiential methods were adopted, including twelve immersive workshops with university professors and a longitudinal study with psychology students. These efforts produced two main outcomes: (i) a *qualitative study* with faculty members, which illuminated perceived pedagogical affordances, challenges, and contextual constraints of immersive teaching (*see* paragraph 1.3); and (ii) a *quantitative longitudinal study* with students, which examined expectation confirmation, perceived usefulness, satisfaction, and continuance intention toward XR learning (*see* paragraph 1.4). Together, these results provided an in-depth understanding of stakeholder perspectives and defined the design requirements for the next phase.

The *Prototype* phase (described in Chapter 2) sought to translate the insights gained during Empathize into concrete design strategies and operational models for XR-based learning. Its objective was to establish both the human and methodological foundations required to design and implement immersive learning experiences in authentic academic contexts. This phase produced two complementary outcomes: (i) the *conceptualization of a new professional role*, the Immersive Learning Designer (ILeaD), envisioned as a bridge between pedagogical, technical, and organizational domains to ensure alignment between learning goals, technological resources, and accessibility needs; and (ii) the *development of the MetaLab Model*, a learner-centered instructional design framework grounded in experiential and transformative learning theories. These outputs jointly enabled the co-design and curricular integration of immersive learning modules, referred to as *MetaLabs*, which were collaboratively developed with faculty members across various disciplines and campuses following participatory design principles.

The *Test and Evaluation* phase (outlined in Chapter 3) aimed to empirically assess the educational impact and experiential quality of the MetaLabs developed in the Prototype phase. Its objective was to validate the MetaLab Model through systematic evaluation of XR-based learning activities conducted in real higher education environments. This phase produced three quantitative studies, each addressing a different analytical dimension of immersive learning: (i) Social, Cognitive, and Affective Experience in two MetaLabs (*see* paragraph 3.1); (ii) Usability, Effort, and Continuance Intention across sixteen MetaLabs MetaLabs (*see* paragraph 3.2); and (iii) Epistemic Emotions, Absorption, Effort, and Motivation to Learn in immersive learning environments (*see* paragraph 3.3). Collectively, these studies provided a comprehensive understanding of how immersive experiences shape engagement, learning processes, and motivational dynamics in university contexts, thereby contributing to the empirical validation of the MetaLab framework.

Finally, some Guidelines and the MetaLab *Toolkit* (presented in Chapter 4) aimed to synthesize the theoretical, methodological, and empirical contributions of the research into a set of actionable resources for educators and instructional designers. The primary outcome of this phase was the MetaLab Toolkit, a collection of practical guidelines, design principles, and co-design tools that translate the knowledge generated throughout the study into accessible strategies for inclusive, effective, and scalable XR-based learning. This final phase thus bridges research and practice, supporting institutions and educators in responsibly integrating immersive technologies into higher education curricula.

The next paragraphs offer a concise, chapter-by-chapter overview designed to guide the reader toward a macro-level understanding of the work.

Overview of the Chapters

Chapter 1. Empathize Phase: Faculty and Student Perspectives about XR in Higher Education

This chapter is dedicated to the *Empathize* phase of the present doctoral research, which investigated faculty and student expectations/ perspectives regarding XR technologies in higher education. The work presented in this chapter is related to two main studies: (i) experiential workshops that involved faculty members and (ii) a longitudinal study involving university students.

For what concerned the first study, twelve 90-minute experiential workshops were run in a purpose-built immersive classroom with 90 faculty members from diverse disciplines. Each session combined a short pedagogical briefing, a guided XR experience featuring avatar-mediated interaction and curated virtual scenarios, and a reflective debrief.

For what concerned the second study, a five-week immersive module was inserted in a psychology course with 32 enrolled students (25 of which participated in the study). The study used a longitudinal design and the Extended Expectation-Confirmation Model to relate pre-adoption beliefs (i.e., performance and effort expectancy) to post-use confirmation, perceived usefulness, satisfaction, self-efficacy, and continuance intention.

Key workshop findings indicate that faculty view XR as a powerful tool for simulating complex scenarios, translating abstract concepts into embodied experiences, enabling remote/ hybrid collaboration, and possibly increasing engagement through gamified, multimodal interactions. However, faculty members also identified important obstacles: device ergonomics and physical discomfort; accessibility and inclusivity concerns for diverse learner needs; limited realism and interactivity in current content; scarcity of discipline-specific educational materials; high development and infrastructure costs; and curricular and logistical integration issues.

Results related to the second study revealed that: (i) contrary to some prior literature, pre-adoption performance and effort expectancies did not predict expectation confirmation following direct experience. This null finding likely reflects the elective, self-selected sample and participants' prior familiarity with digital tools; (ii) the variable *confirmation* (the extent to which actual experience matched expectations) emerged as a strong predictor of post-adoption perceived usefulness ($\beta \approx 1.01$), satisfaction ($\beta \approx 1.06$), and self-efficacy ($\beta \approx 0.64$; (iii) these post-adoption variables robustly predicted continuance intention (perceived usefulness $\beta \approx 0.88$; satisfaction $\beta \approx 0.82$; self-efficacy $\beta \approx 0.83$). Together, the findings highlight experiential congruence, aligning students' expectations with lived XR experiences, as a central point for adoption and sustained use.

Practical implications emphasize the need for experiential, scaffolded introduction to XR, early assessment of student familiarity, accessible/ hybrid deployment modes, faculty co-design and training, and low-cost technical configurations.

Chapter 2. Prototype Phase: the MetaLab Model

Chapter 2 formalizes the *Prototype* phase of the present doctoral work and introduces the "MetaLab" instructional design model, a technology-agnostic, learner-centered framework for designing transformative XR learning experiences while accommodating a continuum of technological access (i.e., fully immersive, semi-immersive, and non-immersive modes).

This chapter articulates three interlocking pillars that underpin the MetaLab model: (i) *experiential learning*, (ii) *transformative learning*, and (iii) *experience-design principles*. The model operationalizes Kolb's experiential cycle (i.e., concrete experience → reflective observation → abstract conceptualization → active experimentation), Mezirow's transformative-learning theory (1991) (notably disorienting dilemmas, critical self-reflection, and dialogic validation) and experience-design principles to constitute the theoretical underpinnings of the model. Congruently, the "MetaLabs", namely, the immersive learning modules that are produced through this framework, are designed to catalyze personal transformation, elicit epistemic emotions (e.g., curiosity, awe, surprise) that deepen cognitive engagement and memory, and enable creative collaboration.

Starting from the insights obtained in the *Empathize* phase, especially those related to the perceived need by faculty members to respond to the technical skills required to deliver XR classes and the actual gap with real competences and infrastructural support, parallelly to the MetaLab model a new figure is presented: the Immersive Learning Designer (ILeaD). The Ilead is a pedagogically informed practitioner who mediates between faculty, technical teams and students, supports co-design with faculty members, orchestrates accessibility strategies, and ensures alignment between learning objectives and technology choices.

The MetaLab instructional workflow is then described as a three-phase co-design process in which both ILeaD and faculty members are involved (along with technical staff if needed). The three phases of the co-design are aimed to, respectively: (i) identify learning goals; (ii) select appropriate XR platforms and content; (iv) test and refine the XR learning experience. A concrete MetaLab case (i.e., *Virtual Tour of Milan's Chinatown*) is also presented to illustrate the workflow. Through this methodology, 16 MetaLabs have been produced by involving (on a voluntary basis) faculty members that participated in the experiential workshops. Lastly, Chapter 2 concludes with the presentation of the students' MetaLab evaluation protocol, which received approval by the Ethical Committee of Università Cattolica del Sacro Cuore di Milano, used to evaluate the MetaLabs experience that will be presented in Chapter 3.

Chapter 3. Test and Evaluation Phase: MetaLab Implementation and Assessment

Chapter 3 presents the *Test and Evaluation* phase of the doctoral research, in which the MetaLab framework was implemented and empirically assessed across multiple university courses and campuses of the Università Cattolica del Sacro Cuore (Milan, Brescia, Piacenza, and Cremona). Building upon the theoretical and design foundations introduced in Chapter 2, this phase evaluates how MetaLabs perform in authentic higher education contexts, combining formative and summative evidence to validate the framework's pedagogical, experiential, and technological robustness.

Study 1 examined students' *social, cognitive, and affective experiences* in two pilot MetaLabs integrated into the master's course "Virtual Reality Techniques and the Metaverse for Well-being" (Milan campus). Both experiences were designed and delivered on the social VR platform *Spatial.io*, exploring embodiment and creativity in immersive learning. Results revealed moderate-to-high levels of social presence, low extraneous cognitive load, and sustained concentration, suggesting that the MetaLab structure effectively supports social connectedness and cognitive efficiency. Emotional responses were dominated by positive epistemic emotions, notably curiosity, enjoyment, and surprise, while frustration, confusion, and boredom remained low. These findings confirm that the MetaLab format can reliably elicit meaningful engagement and positive emotional activation in immersive settings, independent of specific content.

Study 2 expanded the evaluation to sixteen MetaLabs co-designed with faculty members across various disciplines, such as Psychology, Sociology, Economics, Architecture, and Chemistry, and implemented across four campuses. These MetaLabs covered courses including General Psychology (Piacenza), Sociology of Digital Media (Milan), Institutions of Political Economy (Brescia), and Analytical Chemistry (Cremona and Piacenza). The study focused on *usability, perceived effort, and continuance intention* toward XR technologies. Results showed high usability scores ($M = 80.5$, $SD = 13.5$) exceeding the international benchmark, moderate cognitive and physical effort, and a significant negative correlation between usability and workload. Regression analysis identified usability as a strong positive predictor of continuance intention ($R^2 = .16$), indicating that intuitive, accessible designs foster long-term acceptance of XR in academic contexts. These findings underscore that successful XR adoption depends not only on technological sophistication but on user-centered design that minimizes strain and enhances learning comfort.

Study 3 analyzed fourteen MetaLabs presented in Study 2 MetaLabs, focusing on the *emotional, attentional, and motivational mechanisms* underlying immersive learning. The sample included both immersive MetaLabs (e.g., Psychology of New Technologies, Geography Laboratory, Well-being and Positive Technologies) and non-immersive ones (e.g., Analytical Chemistry, History of Contemporary Architecture). Results indicated that positive activating emotions (i.e., curiosity, enjoyment, surprise) and absorption were strong predictors of motivation to learn in both immersive and non-immersive modalities. Students in immersive MetaLabs reported higher emotional arousal and greater cognitive–physical effort, while those in desktop-based MetaLabs achieved comparable motivation with lower workload. This suggests that immersive technologies intensify engagement but also increase attentional and ergonomic demands, whereas non-immersive designs can maintain motivation through well-structured, emotionally resonant activities.

Taken together, the findings confirm that the effectiveness of MetaLabs depends less on the degree of technological immersion than on the quality of the learning experience, its emotional resonance, cognitive manageability, and pedagogical alignment. This phase consolidates the MetaLab framework as an evidence-based, learner-centered, and scalable approach to XR education, forming the empirical foundation for the MetaLab Toolkit presented in Chapter 4.

Chapter 4. Guidelines for Educators and Designers: the MetaLab Toolkit

Chapter 4 translates the research program into a practical, evidence-informed MetaLab *Toolkit* that operationalizes the instructional design model through guidelines, templates, and exemplars for higher-education use. Anchored in Design-Based Research and Design Thinking, the toolkit distills Chapter 3's findings into design principles across four domains: (i) social, cognitive, and affective engagement; (ii) usability, effort, and continuance intention; (iii) epistemic emotions, absorption, and motivation to learn; and (iv) accessibility and inclusion. It frames XR learning as an experience-centered ecosystem in which emotional resonance, cognitive manageability, and pedagogical alignment, not immersion alone, drive effectiveness and sustainable adoption.

The chapter consolidates theory and evidence into actionable guidance: structure XR activities into clear segments with multimodal scaffolds to manage cognitive load; design for curiosity, adaptive challenge, and reflective debriefs to regulate emotions and sustain motivation; cultivate social presence through collaborative tasks and prioritize usability and comfort to reduce effort and strengthen continuance intention. Accessibility is treated as constitutive rather than corrective, with Universal Design for Learning and neuroinclusive principles informing multimodal access, flexible inputs and postures, dual-mode delivery (immersive and non-/semi-immersive equivalents), and proactive onboarding and support.

To make co-design replicable, the toolkit provides three reusable templates: (i) the *Profiling Sheet*; (ii) *Prototyping Shee*t, and (iii) *Consolidation & Validation Sheet*, that capture goals, constraints, platform/content choices, activity flow, logistics, evaluation, and accessibility provisions, illustrated through the "Geography with Laboratory" case. Finally, the chapter offers an institutional roadmap for scaling from pilots to program- and platform-level adoption, emphasizing governance, open standards (e.g., OpenXR), GDPR-compliant procurement, shared services and training, dual-mode parity, and embedded formative evaluation. In sum, Chapter 4 reframes XR implementation as a disciplined, inclusive, and evidence-driven design practice, enabling universities to scale MetaLabs with pedagogical integrity and equity.

1. Empathize Phase: Faculty and Student Perspectives about XR in Higher Education

Before presenting the studies conducted during the *Empathize phase*, an excursus on the historical evolution of education will be provided, tracing its progression from earlier paradigms to the current framework of Education 4.0, which incorporates XR technologies (Milgram & Kishino, 1994). This overview will also outline the key psychological constructs associated with each stage of educational development, thereby situating the present research within its psychological-theoretical context.

1.1 XR in Higher Education: A Review of Current Research

1.1.1 Evolution of Education: from Education 1.0 to 4.0

The conceptual evolution of education has been described as unfolding across successive phases, culminating in what is now commonly referred to as *Education 4.0*. While there is general agreement that the emergence of Education 4.0 coincides with the advent of Industry 4.0 around 2011 (Chakraborty et al., 2023), scholarly debate persists concerning the temporal demarcation of its preceding stages. Aliyu et al. (2020) argue that the educational eras correspond directly to the historical trajectory of the Industrial Revolutions (Fig. 6). In this perspective, Education 1.0 is situated in the late eighteenth to early nineteenth century, reflecting the pedagogical models associated with the First Industrial Revolution. Education 2.0 and 3.0, in turn, are aligned with the Second and Third Industrial Revolutions, respectively, each phase progressively incorporating the technological and socio-economic transformations of its time.

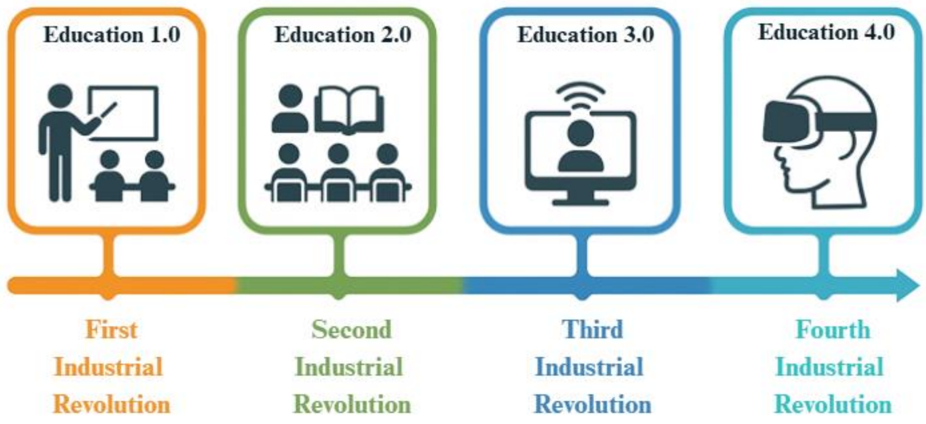


Fig. 6. Conceptual evolution of Education from Education 1.0. to Education 4.0

Conversely, other scholars propose a framework that anchors educational eras in the digital domain, specifically in the development of the World Wide Web. Huk (2021) and Butt et al. (2020) contend that Education 1.0, 2.0, and 3.0 parallel the transitions from Web 1.0 through Web 3.0. According to this interpretation, Education 1.0 emerges in the 1980s with the diffusion of Web 1.0, characterized by static information transmission. The participatory affordances of Web 2.0 in the early 2000s underpin Education 2.0, marking a shift toward interactivity and learner agency. Finally, Web 3.0 technologies and principles, such as semantic interoperability, personalization, and intelligent systems, are regarded as foundational to Education 3.0. This divergence highlights a broader epistemological tension in literature: whether educational transformation should be primarily understood as a function of macro-industrial revolutions or as a reflection of the digital-communication paradigms brought forth by the Web. Despite differences in chronological framing, both perspectives converge in recognizing a progressive reconfiguration of the learner's role, from passive recipient in Education 1.0, to active participant in Education 2.0 and 3.0, and ultimately to central agent of learning in Education 4.0.

Although there is no consensus on the precise starting points of the different educational eras, scholars tend to converge in their descriptions of their defining characteristics. *Education 1.0* is generally depicted as a teacher-centered paradigm, rooted in transmissive pedagogy where knowledge flows unidirectionally from instructor to student, and learners are positioned as passive recipients (Aliyu et al., 2020; Anderson & Dron, 2011). This model emphasizes authority, standardization, and the reproduction of knowledge, closely aligned with traditional schooling practices.

Several experimental and progressive pedagogical approaches laid the conceptual foundations of subsequent phases. Early constructivist and experiential traditions emphasized learning as an active, embodied, and multisensory process grounded in direct interaction with the environment. For instance, the pedagogical approach developed by Maria Montessori foregrounded the role of bodily engagement, sensorimotor exploration, and material interaction as central mechanisms of cognitive development (Colgan, 2016). Similarly, John Dewey conceptualized learning as a process emerging from experience, action, and reflection, arguing that knowledge is constructed through meaningful interaction with real-world situations rather than passive transmission (Dewey, 1986). In parallel, constructivist theories of cognitive development, such as those proposed by Jean Piaget, highlighted the importance of active manipulation and exploration of the environment in the formation of mental structures (Piaget, 1952), while socio-cultural perspectives, notably Lev Vygotsky, emphasized the situated and socially mediated nature of learning processes (Vygotsky, 1978). More recent perspectives in embodied cognition further reinforced these ideas by demonstrating that cognitive processes are deeply rooted in bodily states, perception, and action (Wilson, 2002; Barsalou, 2008). Taken together, these approaches contributed to a progressive shift from abstract, disembodied instruction toward educational models that privilege experience, perception, movement, and interaction. From this perspective, XR technologies can be understood not as a pedagogical rupture, but as a technological extension of long-standing educational principles that have consistently emphasized embodied, situated, and multisensory learning. The ways in which these principles are operationalized and amplified through digital technologies.

A gradual transition emerges in *Education 2.0* and *Education 3.0*, which reflect increasing levels of learner agency and interactivity. Education 2.0, associated with the affordances of Web 2.0, is characterized by collaborative learning, participatory knowledge construction, and a stronger emphasis on student proactivity (Huk, 2021; Redecker, Ala-Mutka & Punie, 2010). Education 3.0 advances this trajectory further by integrating semantic and intelligent technologies that enable adaptive, personalized, and networked learning environments (Bongomin, et al., 2020; Redecker & Punie, 2017). In both phases, learners are encouraged to move beyond passive consumption toward active engagement in the co-creation and sharing of knowledge.

In contrast, *Education 4.0* signifies a paradigmatic shift in which the learner is recognized as the central agent of the educational process, empowered by the technological ecosystem of Industry 4.0. This model emphasizes self-directed, flexible, and technology-enhanced learning, incorporating artificial intelligence, immersive technologies, and data-driven personalization (Costan et al., 2021; Miranda et al., 2021). The aim is not only to equip students with disciplinary knowledge but also to cultivate transversal skills such as critical thinking, creativity, collaboration, and digital literacy, skills deemed essential for thriving in the Fourth Industrial Revolution (Van Dam, 2017; Goh & Abdul-Wahab, 2020).

Thus, despite discrepancies in temporal framing, the literature reveals a coherent narrative of progressive educational transformation: from hierarchical, knowledge-transmission models in Education 1.0 to learner-centered, technology-mediated ecosystems in Education 4.0 (Bonfield et al., 2020; Sharma et al., 2025). Allowing for a fuller understanding of the transition toward the most recent educational era requires recognizing that the process does not merely entail the adoption of advanced technologies, but rather a profound paradigm shift in the very conception of education. Educational transformation is not reducible to technological substitution or augmentation; instead, it reflects a reconfiguration of pedagogical approaches, epistemological assumptions, and the dynamics of interaction among students, instructors, and educational content (Anderson & Dron, 2011; Miranda et al., 2021). Whereas earlier models of education emphasized transmissive, teacher-centered practices, contemporary frameworks increasingly foreground learner autonomy, collaboration, and the co-construction of knowledge. In this sense, the emergence of Education 4.0 symbolizes not only the integration of technologies derived from Industry 4.0, such as artificial intelligence, immersive environments, and data-driven personalization, but also a reconceptualization of the purposes and practices of education itself (Costan et al, 2021). Learning is no longer understood solely as the passive acquisition of predefined content; it is reframed as an active, adaptive, and networked process in which learners function as central agents, shaping their own educational trajectories in dialogue with peers, instructors, and intelligent systems (Redecker & Punie, 2017; Sharma et al., 2025).

Thus, the shift from earlier educational eras to Education 4.0 represents a dual transformation: one technological, marked by the affordances of digital and intelligent systems, and one paradigmatic, characterized by a move toward student-centered, flexible, and participatory models of teaching and learning. This dual perspective enables a more holistic interpretation of educational change, acknowledging that innovations in technology acquire transformative significance only insofar as they are embedded within new conceptualizations of how education is designed, experienced, and valued.

1.1.2 The Basis of XR Education

Education 3.0 responds to the demand for technological integration (mainly with web interfaces) while fundamentally reshaping roles, processes, and environments in learning: teachers shift from authoritative transmitters of content to facilitators, coordinators, and learning designers, whereas students assume central agency as active participants and knowledge creators, often working with open resources and platforms (Butt et al., 2020).

Characteristic of this approach is the systematic use of e-learning ecosystems that articulate three complementary modalities (Fig. 7): (i) synchronous (e.g., real-time web-conferencing and live chat), (ii) asynchronous (e.g., recorded micro-lectures, readings, forums, and digital libraries), and (iii) blended/ hybrid designs (purposeful orchestration of the first two), each with distinct interactional affordances. Synchronous formats emphasize immediacy, social co-ordination, and rapid feedback; asynchronous spaces afford reflection, self-regulation, and deeper elaboration; blended designs sequence these affordances to fit the knowledge and performance demands of a course (Hrastinski, 2008; Amiti, 2020).

Fig. 7. E-learning ecosystem of Education 3.0 comprehending synchronous, asynchronous and blended modalities. AI-generated images created with ChatGPT [OpenAI, GPT-5, 2025 version].

The core added value of synchronous learning is *immediacy*: real-time exchanges reduce *transactional distance* and enable co-regulation of learning (Moore, 1989). Simultaneous presence elevates social presence, the felt sense of "being with others" online, which reliably predicts satisfaction and relates positively to perceived learning (Gunawardena & Zittle, 1997; Richardson et al., 2016), aligning with the Community-of-Inquiry (CoI) view[8] that equilibrates *teaching*, *cognitive*, and *social presence* to support affective appraisals and achievement. Instructor immediacy behaviors (prompt feedback, warm tone, personal cues) support attention and engagement especially if the learning process is supported by specific elements as the ones described in the ARCS model of motivational design (Keller, 1987a, 1987b, 2009): Attention (A) is gained via variability, signaling, provocative questions, polls, and brief demonstrations that disrupt routine; Relevance (R) is established by framing tasks with authentic cases, motive-matching (e.g., professional goals), and explicit value links to learners' contexts; Confidence (C) is built through clear success criteria, scaffolded practice, controllable pacing, and frequent formative feedback during live activities; and Satisfaction (S) is supported by debriefs, opportunities to apply learning immediately, informational praise/recognition, and equitable assessment (Keller, 1987a, 1987b, 2009). Affective dynamics cut both ways: well-calibrated challenges can foster flow, but multitasking across chat, slides, and video may heighten anxiety and cognitive load if poorly designed (Pekrun, 2006; Pekrun, 2014; Sweller, 2005; Mayer, 2014).

Asynchronous learning, by affording substantial temporal and procedural control over access to materials and task completion, creates an autonomy-supportive climate consistent with Self-Determination

[8] The Community of Inquiry (CoI) framework posits that effective online and blended learning emerges from the purposeful integration of three interdependent elements: (i) teaching presence (design, facilitation, and direction of learning), (ii) social presence (the extent to which participants present themselves as real, relational others), and (iii) cognitive presence (the iterative inquiry process through which learners construct and apply meaning). Foundational work established the model and its pedagogical logic, subsequent studies provided validated instruments to measure these elements in online/ blended learning (Garrison, Anderson, & Archer, 1999; Garrison & Arbaugh, 2007; Arbaugh et al., 2008; Richardson et al., 2017).

Theory (Deci & Ryan, 2012) and thereby catalyzes self-regulated learning and metacognition (Zimmerman, 2002; Broadbent & Poon, 2015; Chen & Jang, 2010). The opportunity to plan, monitor, and adjust one's study trajectory enables deeper processing through generative activities (e.g., explanatory writing, concept mapping), which foster knowledge construction (Fiorella & Mayer, 2015). In parallel, self-pacing facilitates the adoption of spaced practice and retrieval practice, both linked to durable retention and transfer (Roediger & Karpicke, 2006; Dunlosky et al., 2013). Motivationally, frequent low-stakes quizzes, iterative drafts, and informational feedback provide clear progress signals that strengthen perceived competence, while well-structured forums and peer review satisfy relatedness needs and sustain social presence, a reliable correlate of satisfaction and perceived learning in online environments (Richardson et al., 2017) Emotionally, curiosity and productive confusion can catalyze inquiry when guided, whereas unguided confusion may drift into frustration (D'Mello & Graesser, 2012; Pekrun, 2006; Loderer, Pekrun, & Lester, 2020). Finally, flexible timing mitigates cognitive load and evaluative anxiety, supporting achievement-facilitating emotions such as interest and enjoyment (Sweller, 2005; Pekrun, 2006). In sum, the temporal flexibility and choice architecture of asynchronous designs jointly maximize autonomy, reflection, and strategic regulation, satisfying basic psychological needs (autonomy, competence, relatedness) that underpin motivation and performance in digitally mediated learning (Deci & Ryan, 2020; Chen & Jang, 2010).

In blended learning, instruction deliberately orchestrates the immediacy of synchronous sessions (social coordination, rapid feedback) with the reflective depth of asynchronous study (self-pacing, extended processing) under the guidance of the Cognitive Theory of Multimedia Learning (CTML). CTML posits that effective learning from words and pictures hinges on respecting (i) dual channels for processing (auditory–verbal and visual–pictorial), (ii) the limited capacity of each channel, and (iii) the learner's need for active processing, that is, selecting relevant information, organizing it into coherent structures, and integrating it with prior knowledge (Mayer, 2005). From these assumptions follow concrete design principles: signaling to guide attention to key elements (Mautone & Mayer, 2001); segmenting with learner pace control to break complexity into manageable micro-units (Mayer & Chandler, 2001); modality (pairing graphics with spoken narration) and redundancy avoidance (eschewing duplicated on-screen text) to balance channel load (Mayer & Chandler, 2001); spatial/temporal contiguity to align words and visuals; and coherence to remove seductive but irrelevant details (Mayer, 2005). Operationally, this means asynchronous micro-lectures designed as short, cued clips with embedded checks, synchronous sessions that "talk to" diagrams rather than read text-heavy slides, and regular retrieval-practice + feedback cycles to consolidate understanding, complemented by generative activities (e.g., explanatory writing, concept mapping) that deepen organization and integration (Dunlosky et al., 2013; Sweller, 2005). Used coherently, these principles reduce extraneous load, titrate intrinsic load, and maximize germane processing, turning the synch/async blend into a cognitively efficient and instructionally effective learning environment.

Comparative research corroborates the value of this orchestration: in technology and STEM contexts, blended learning often yields the strongest cognitive gains. A quasi-experiment in technology education showed blended outperformed synchronous and asynchronous conditions on formative and summative assessments (Calago et al., 2024), and a meta-analysis reported larger effects for blended versus traditional instruction in science/engineering (Hedges' g = 1.017) than in the humanities (g = 0.795; Shi, Wu, & He, 2025). Head-to-head contrasts between synchronous and asynchronous formats are mixed and appear task-contingent: one meta-analysis found a small cognitive advantage for synchronous online learning (Martin et al., 2021), whereas another detected a slight advantage for asynchronous delivery on knowledge outcomes with trivial overall effects and little moderation by level or discipline (Zeng & Luo, 2023).

Building on these insights, Education 4.0 extends the design space beyond the two-dimensional web interface to immersive and mixed environments, thereby introducing or amplifying the need to consider psychological constructs interviewing in the learning process.

1.1.3 Education 4.0: XR Taxonomy and Features

Education 4.0 is best understood as a learning-centred paradigm that consolidates and extends the shifts initiated under Education 3.0 toward agency, personalization, and authentic competence development. In this framing, technology is instrumental rather than determinative: Education 4.0 organizes learning around a set of general principles. According to Fisk (2017) central to this paradigm are the personalization and flexibility of learning pathways, allowing students to adapt methodologies and select tools according to their needs while pursuing shared objectives. Instructional design emphasizes project-based and experiential approaches, encouraging the development of applied competencies, collaboration, and practical skills. At the same time, the automation of routine processes enhances the relevance of human reasoning and interpretive abilities. Assessment practices are shifting toward continuous, competency-based models grounded in authentic tasks, while student involvement in curriculum design and the promotion of independent, mentored learning further strengthen autonomy and ensure alignment with societal and professional demands.

1.1.3.1 XR Taxonomy

Extended Reality (XR) has emerged as an umbrella concept that encompasses a wide range of technologies designed to extend human perception and action through digital mediation. The term generally includes Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR) and began to gain traction in the second half of the 2010s, when advances in hardware, software, and connectivity made immersive technologies more affordable and accessible. Although VR systems had been investigated since the 1960s in research laboratories (Sutherland, 1965), and AR was first introduced in the 1990s (Azuma, 1997), it was only with the popularization of consumer-grade head-mounted displays such as the Oculus Rift (2016) and Microsoft HoloLens (2016) that the academic discourse adopted XR as a comprehensive category. The term reflects the convergence of multiple modalities of immersion and augmentation under a single framework, enabling researchers and practitioners to conceptualize them not as isolated tools but as part of a continuum of human–computer interaction.

The conceptual foundation of XR can be traced back to the Virtuality-Reality Continuum (Fig. 8) proposed by Milgram and Kishino (1994) in their seminal article *A Taxonomy of Mixed Reality Visual Displays*. This framework emerged from the need to classify and conceptualize the increasing variety of computer-mediated environments that, at the time, could not be adequately described by the existing dichotomy between *virtual reality* and *telepresence*. Milgram and Kishino (1994) observed that novel display technologies (e.g., head-mounted see-through systems, video overlays, and teleoperation interfaces) were progressively enabling the coexistence and integration of physical and digital stimuli within the same perceptual field. To account for this hybridization, they introduced the concept of a continuum that positions the real environment at one extreme, where all sensory input derives directly from the physical world, and the completely virtual environment at the opposite extreme, where all perceptual stimuli are computer-generated. The intermediate region, termed Mixed Reality (MR), includes all configurations in which real and virtual elements are combined in real time, allowing the user to interact simultaneously with both domains (Milgram & Kishino, 1994).

In developing this model, Milgram and Kishino (1994) sought to provide a systematic taxonomy of mediated environments that could describe not only the visual blending of real and virtual content but also the underlying degrees of technological mediation. They proposed three analytical dimensions to characterize these systems: the extent of world knowledge, referring to the degree to which the system internally models or understands the physical environment; the reproduction fidelity, which concerns the accuracy and realism of the mediated representation in spatial, visual, and temporal terms; and the extent of presence metaphor, denoting the user's perceived sense of being located within a coherent and interactive environment. These parameters reflected the authors' intention to conceptualize mediation as a continuum of representational and perceptual states, rather than a binary opposition between the real and the virtual.

The development of the VR Continuum was informed by empirical research on stereoscopic vision, telepresence robotics, and video see-through interfaces, carried out in the early 1990s at the University of Toronto's Human Interface Technology Laboratory. Milgram and Kishino (1994) drew upon these studies to argue that when virtual objects are spatially registered and temporally synchronized with the user's perception of the real world, the resulting hybrid environment produces a novel perceptual condition that cannot be classified as purely physical or purely virtual. The continuum was thus conceived as an analytic framework for understanding real–virtual fusion as both a perceptual and technological phenomenon, emphasizing that mediated experiences occur along a graduated spectrum of virtuality determined by the level of digital augmentation or substitution.

Later elaborations by Milgram and Colquhoun (1999) further refined this taxonomy by distinguishing between Augmented Reality (AR), in which digital information is superimposed onto the physical environment, and Augmented Virtuality (AV), in which real-world sensory data are incorporated into an otherwise virtual space. This bidirectional interpretation underscored the fluid and context-dependent boundary between real and virtual environments, emphasizing that Mixed Reality represents not a single technology but a conceptual domain encompassing multiple forms of hybrid perception. Through this perspective, Milgram and Colquhoun (1999) provided an early theoretical foundation for understanding the progressive integration of tracking, registration, and real-time feedback systems, which would later become defining features of contemporary XR.

By presenting reality and virtuality as a continuous perceptual and technological spectrum, the VR Continuum offered one of the first systematic attempts to describe how digital augmentation and virtual substitution can coexist within mediated environments. This model has since exerted a lasting influence on research in human–computer interaction, telepresence, and immersive learning, establishing a conceptual vocabulary that continues to inform how XR systems and experiences are analyzed and designed.

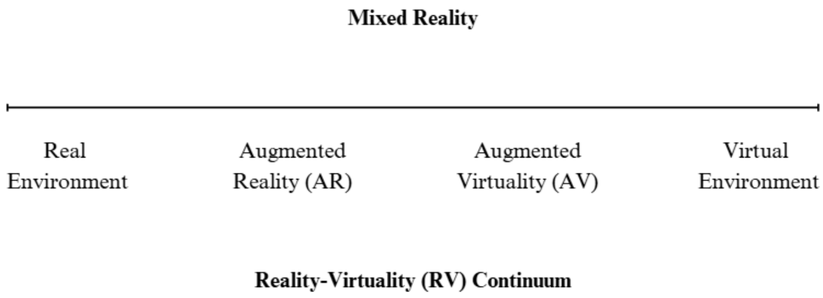


Fig. 8. VR Continuum (Milgram & Kishino, 1994).

While historically influential, the continuum has been criticized for its visual bias and for its inability to fully account for contemporary developments such as multisensory immersion, sensorimotor integration, and multimodal interaction (Mann et al., 2018). Indeed, the model implicitly equates the degree of immersion with the manipulation of visual information along a real–virtual spectrum. This emphasis on vision, while historically justified by technological constraints, becomes increasingly problematic when XR experiences are examined from a cognitive and educational perspective. Contemporary research in multisensory perception demonstrates that human experience is inherently multimodal and that perceptual coherence emerges from the integration of multiple sensory channels rather than from vision alone (Shams & Seitz, 2008; Stein & Stanford, 2008). In learning contexts, multisensory integration has been shown to facilitate attention, conceptual grounding, and memory consolidation, suggesting that sensory richness is not a peripheral feature but a core determinant of learning effectiveness. From the perspective of embodied and grounded cognition, cognitive processes are inseparable from bodily states, sensorimotor contingencies, and action–perception loops, which extend beyond the visual modality (Barsalou, 2008; Wilson, 2002). By privileging vision, the classical Reality–Virtuality Continuum risks obscuring critical experiential differences between XR systems that may be visually comparable yet differ substantially in their support for auditory feedback, haptic interaction, proprioceptive cues, or vestibular stimulation. This limitation is particularly salient in immersive learning environments, where the sense of presence, agency, and engagement depends on the coordinated activation of multiple sensory systems (Riva et al., 2019). As a result, visually focused models may underestimate the pedagogical value of XR applications that leverage non-visual modalities to support understanding, emotional involvement, and embodied meaning-making. For these reasons, several scholars have argued that traditional continuum-based models should be complemented by frameworks that explicitly address multisensory and embodied dimensions of experience, especially when XR technologies are designed and evaluated for educational purposes.

From this critical aspect and building upon Milgram and Kishino's (1994) VR Continuum, subsequent scholarship has sought to move beyond the limitations of a unidimensional model by introducing additional axes capable of capturing the complexity of technologically mediated experiences. Mann and colleagues (2018) advanced the concept of *Mediality*, defined as the degree to which reality is deliberately modified rather than replaced. This dimension spans from slight alterations to radical transformations of the physical environment. Classic perceptual experiments, such as Stratton's (1897) use of inverted vision glasses, exemplify high mediality in the absence of virtuality, while contemporary technologies like helmets demonstrate selective augmentation of human perception.

Mann et al. (2018) further elaborated the framework of *Multimediated Reality*, which incorporates multi-scale and multi-veillant dimensions while emphasizing the role of *Humanistic Intelligence (HI)*, a paradigm in which humans remain embedded within the computational feedback loop. A central feature of this model is the reciprocity between *surveillance* and *sousveillance* (Mann, Nolan, & Wellman, 2003). *Surveillance* refers to observation "from above," typically enacted by governments, institutions, or corporations (e.g., cameras in public spaces), whereas *sousveillance* refers to observation "from below," in which individuals use wearable or mobile technologies to record and monitor their surroundings, including the actions of authorities. This interplay highlights that humans are not merely passive objects of monitoring but can also act as active agents in distributed systems of observation.

Mann et al. (2018) also introduced additional axes that articulate how mediated technologies shape perception and cognition. *Phenomenality* refers to the capacity of devices to render perceptible phenomena that ordinarily remain invisible, such as SWIM (Sequential Wave Imprinting Machine) systems that allow to visualize acoustic waves. *Wearability* concerns not just the ability to wear a device, but the seamless embedding of computational systems into the body's habitual interface, as seen in head-mounted displays or smart glasses. *Kineveillance* focuses on motion-based monitoring, describing systems that detect and respond to bodily or environmental movements, with applications ranging from health and rehabilitation to behavioral tracking. Finally, *Therapality* designates the persistence of perceptual, cognitive, or affective effects even after the removal of the technological apparatus. For instance, prolonged use of VR headsets can temporarily alter balance and spatial perception (LaViola, 2000; Stanney, Kennedy, & Kingdon, 2002), while immersive learning tools have been shown to produce enduring cognitive and emotional transformations, influencing engagement, memory, and motivation beyond the immediate experience (Makransky, Terkildsen, & Mayer, 2019; Parong & Mayer, 2018). Together, these dimensions foreground a vision of mediated reality not as an external representational layer but as a constitutive element of human perceptual and social experience.

In parallel, Skarbez, Smith, and Whitton (2021) proposed the *EWK–IM–CO Taxonomy*, which reconceptualizes Mixed Reality through three interrelated dimensions that integrate system capabilities with user interpretation. The *Extent of World Knowledge (EWK)* reflects the degree to which the system accurately models real-world contextual features such as spatial layout, identity, and object functionality. *Immersion (IM)* is defined not merely by sensory fidelity but by the range of valid actions afforded by the system, combining Milgram's (1994) notion of *reproduction fidelity* with Slater and Wilbur's (1997) *extent of presence metaphor*. Finally, *Coherence (CO)* concerns the consistency with which system intentions are conveyed and interpreted, whether through reliable integration of real and virtual entities in AR or through internally consistent interactions in VR.

Taken together, these expanded frameworks illustrate the limits of conceiving Extended Reality through a purely visual or linear continuum. Instead, they advocate multidimensional models that account for the interplay of mediation, embodiment, action, and coherence. By integrating perspectives such as Mann's (2018) multimediated axes and Skarbez et al.'s (2021) tripartite taxonomy, the field moves toward richer and more comprehensive theoretical tools capable of describing the diversity of contemporary XR technologies and experiences.

1.1.3.2 XR Technologies in Education

As described before, XR encompasses a broad spectrum of technologies that differ not only in their technical infrastructure but also in the degree of immersion they provide for the user. Let's consider the VR Continuum (Milgram & Kishino, 1994).

At one end of this continuum lies AR, which overlays digital content, such as images, 3D models, or text, onto the physical environment while preserving continuous access to the real world. Typically delivered through mobile devices, tablets, or lightweight head-mounted displays capable of spatial registration and real-time rendering (Azuma, 1997; Billinghurst, Clark, & Lee, 2015), AR supports situated learning experiences in which the physical and digital seamlessly intersect. For example, in anatomy education, AR applications allow students to scan printed materials with a tablet or smartphone, triggering the appearance of three-dimensional organ models that can be rotated, enlarged, or explored in detail (Kucuk, Kapakin, & Goktas, 2016).

Progressing along the immersion spectrum, MR enables real and virtual objects to coexist and interact dynamically. Unlike AR, which primarily superimposes digital elements, MR anchors holographic objects into the physical environment, allowing users to manipulate them as though they were tangible (Milgram & Kishino, 1994). This is made possible by devices such as Microsoft's HoloLens, which integrate spatial mapping, depth sensing, and gesture recognition (Stevenson & Lindberg, 2010). In medical education, for instance, MR simulations allow learners to explore complex neuroanatomical structures by walking around holographic brains, interacting with them through gestures, and collaborating with peers viewing the same content (Moro et al., 2017). By combining embodiment, collaboration, and spatial interaction, MR achieves a moderate-to-high degree of immersion: users remain connected to the real environment but experience virtual elements as part of their lived space (Slater & Sanchez-Vives, 2016).

At the opposite end of the spectrum lies VR, which immerses users in fully computer-generated environments that substitute real-world sensory input. Delivered through head-mounted displays such as Oculus Quest or HTC Vive, often complemented by controllers, motion tracking, and haptic devices (Sherman & Craig, 2019; Slater & Sanchez-Vives, 2016), VR is characterized by a high level of sensory fidelity and spatial presence. In higher education, VR has been applied to public speaking training, where learners rehearse presentations in simulated lecture halls populated by virtual audiences, benefiting from automated feedback on voice, posture, and eye contact (Radianti et al., 2020). VR laboratories in science and engineering also enable students to safely engage with dangerous or costly experiments in a virtual setting, ensuring both accessibility and experiential depth (Bailenson, 2018). This capacity to create a strong "sense of being there" (Slater, 2003) makes VR the technology that achieves the highest degree of immersivity among current XR tools.

Building upon these modalities, the concept of the *metaverse* extends immersion into a persistent, networked, and socially shared environment where users, represented by avatars, can interact with each other and with digital objects in real time. Unlike standalone VR or MR applications, the metaverse emphasizes interoperability, persistence, and social presence (Dionisio, Burns, & Gilbert, 2013). In educational contexts, platforms such as Second Life have enabled students to attend lectures, collaborate on projects, and engage in simulations within shared virtual campuses (Salmon, Nie, & Edirisingha, 2010). Another notable example is Minecraft, a sandbox-based virtual world initially designed as a game and later adapted for educational use through structured learning editions and pedagogical frameworks (Andersen & Rustad, 2022; Sánchez-López et al., 2022). Research has documented Minecraft's potential to support a range of educational outcomes, including creativity, collaboration, problem-solving, motivation, engagement, and 21st-century skills, as well as its use in enhancing students' spatial thinking and conceptual understanding when integrated into formal curricula (systematic reviews; Di Leo & Traetta, 2025; Darmawan et al., 2025).

Owing to its open-ended, immersive, and interactive nature, Minecraft exemplifies how game-based virtual environments can be repurposed as metaverse-like educational spaces that align with core principles of experiential and constructivist learning, thereby expanding the conceptualization of the educational metaverse beyond platforms that were initially created explicitly for educational purposes. More recent solutions, such as EngageVR and Spatial, expand these possibilities by hosting large-scale immersive conferences, workshops, and virtual campuses. The degree of immersion in the metaverse varies according to the access device: desktop use affords symbolic immersion through avatars and interaction, whereas VR headsets enable high levels of presence, embodiment, and co-presence within the same shared digital world.

Finally, AI increasingly acts as a catalyst that enhances immersion across all XR technologies. AI-driven systems, ranging from natural language processing and computer vision to generative algorithms, can support adaptive and personalized interactions (Luckin, Holmes, Griffiths, & Forcier, 2016). In language learning, for example, AI-powered VR environments simulate real-life scenarios such as cafés or airports, where students interact with non-player characters capable of recognizing and interpreting speech in real time (Hooshyar et al., 2021). The system provides immediate corrective feedback on vocabulary, grammar, and pronunciation, thereby fostering linguistic competence and confidence. While AI does not directly increase sensory fidelity, it amplifies cognitive and social immersion by making virtual interactions adaptive, responsive, and believable (Dede, 2009). In this way, AI not only extends the boundaries of immersive learning but also ensures that experiences are dynamically tailored to learners' needs.

1.1.3.3 Psychological Features of XR technologies

Presence

Within the psychology of mediated experiences, the integration of XR into educational contexts requires attention to a set of interrelated psychological constructs that explain how technological affordances translate into meaningful learning outcomes. At the foundation lies the construct of *presence*, defined as the subjective state of "being there" in a mediated environment (Slater & Wilbur, 1997; Lombard & Ditton, 1997). Presence has represented a central focus in VR research since Steuer's (1992) definition of *telepresence* as the extent to which one feels present in a mediated environment rather than in the immediate physical world. It is typically distinguished from *immersion*, which refers, as outlined before, not to a psychological state but to the objective properties of the system, namely, its capacity to provide vivid, multimodal, and interactive stimuli while minimizing competing cues from the real environment (Slater, 2003). This distinction aligns with the model proposed by Slater (1999, 2003), where immersion is conceived as a property of the medium, while presence reflects the user's subjective response.

Empirical evidence supports the link between immersion and presence but highlights its complexity. For instance, Cummings and Bailenson's (2016) meta-analysis of 115 studies demonstrated that not all immersive features exert equal influence: motion tracking and high degrees of freedom in user input ($r = .408$), stereoscopic vision, and large field of view have substantial effects, whereas resolution or audio fidelity improvements show comparatively weaker impacts. This suggests that immersion facilitates presence, but presence emerges only when perceptual, cognitive, and affective processes align.

Slater (2009) further advanced this understanding through the dual-component model of presence, distinguishing between *Place Illusion (PI)*, the perceptual conviction of being located in a mediated space and *Plausibility Illusion (Psi),* the credibility that events occurring within that space are truly happening. PI is primarily dependent on system features such as tracking accuracy, stereoscopy, and latency reduction, while Psi depends on narrative coherence, content credibility, and social dynamics. The implication is that effective XR learning environments must not only maximize immersion (supporting PI) but also foster meaningful, contextually relevant, and socially coherent interactions (supporting Psi) (Slater, 2009).

Parallel to Slater's approach, Witmer and Singer's (1998) theory of presence emphasizes the construct of *involvement*, defined as the allocation of attentional resources and the reduction of awareness of external distractions. This model suggests that presence is sustained when the system captures the learner's attention and channels it into task-relevant stimuli, supporting deeper engagement. Similarly, Lombard and Ditton (1997) described presence as a perceptual illusion of non-mediation, underscoring how the subjective sense of immediacy arises when the medium itself fades from awareness.

Building on these models, research has increasingly conceptualized presence as a multidimensional construct (Lee, 2004; Hartmann et al., 2015). Three key dimensions are particularly relevant in educational XR: *spatial presence*, or the sensation of being physically located in a mediated environment, rooted in perceptual and attentional mechanisms (Hartmann et al., 2015; Wirth et al., 2007); *social presence*, defined as the extent to which others are experienced as "real" within the mediated context (Biocca, Harms, & Burgoon, 2003), often operationalized in collaborative XR learning scenarios where the perception of peers' co-presence fosters communication and joint problem-solving; *self-presence*, referring to the sense of embodiment and agency in a virtual body (Lee, 2004; Ratan, 2012), which is crucial for identity-related learning processes, such as perspective-taking or empathy development in role-playing simulations.

More recently, the framework proposed by Riva and Waterworth (2003) and Waterworth and Riva (2014) offers a particularly comprehensive account by linking presence to the functioning of human consciousness and embodied action. According to this model, presence arises from the brain's ability to represent and regulate the self within an environment through sensory and motor processes. Riva and Waterworth (2003) identify three hierarchical levels of presence: proto-presence, presence, and social presence. *Proto-presence* refers to the lowest and most immediate level of bodily engagement, in which the individual maintains sensorimotor control and awareness of their body in space, an essential prerequisite for any immersive interaction. The second level, *presence*, involves the perceptual and attentional alignment between the self and the mediated environment, allowing the user to experience the virtual setting as a coherent and meaningful spatial reality. Finally, *social presence* (or *extended presence*) denotes the capacity to perceive and relate to others, real or virtual, as intentional agents within the same mediated space, thus extending the sense of "being there" into the interpersonal domain (Waterworth & Riva, 2014).

This tripartite model situates presence as a dynamic and embodied process rather than a static state, emphasizing the interaction between perception, action, and social cognition. It also underscores the multilevel nature of immersion, showing that technological affordances (e.g., tracking accuracy, sensory fidelity) and cognitive mechanisms (e.g., attention, emotion, empathy) jointly determine the depth and quality of the presence experience. In the context of XR learning, this framework provides a valuable interpretive lens for understanding how students engage cognitively, emotionally, and socially with virtual environments, and how design choices can modulate the balance between bodily involvement, attentional focus, and interpersonal connection.

Finally, when discussing immersion in XR environments, it is important to acknowledge the variety of instruments that have been developed to assess this construct. Traditionally, immersion and closely related experiences such as presence have been measured using self-report questionnaires, including widely adopted instruments such as the Presence Questionnaire and the Igroup Presence Questionnaire, which capture users' subjective perceptions of involvement, realism, and attentional engagement (Witmer & Singer, 1998; Schubert, Friedmann & Regenbrecht, 2001). Beyond self-report measures, several studies have highlighted the potential of physiological indicators, such as heart rate variability, electrodermal activity, and electroencephalographic signals, to provide more objective and continuous markers of immersion and engagement (Brouwer et al., 2015). However, the use of these instruments poses significant challenges in real-life educational contexts, as they often require intrusive equipment, controlled laboratory settings, and complex data processing, thereby limiting ecological validity and scalability. Recent advances in wearable technologies offer promising avenues to partially bypass these limitations by enabling the unobtrusive collection of physiological data in naturalistic settings. Wearable sensors integrated into smartwatches, wristbands, or lightweight head-mounted devices allow for the monitoring of physiological responses with reduced interference in the learning activity, thus potentially supporting more ecologically valid assessments of immersion (Peake, Kerr & Sullivan, 2018; Grassini & Laumann, 2020).

Embodiment and Agency

Closely connected to self-presence are the constructs of *embodiment and agency*, which have received significant attention in the psychology of mediated experiences and XR research. Embodiment is generally defined as the illusion of owning and controlling a virtual body (Kilteni, Groten, & Slater, 2012). It is not a unitary construct but rather composed of three interrelated components: *body ownership*, the feeling that the virtual body belongs to oneself; *agency*, the subjective sense of controlling its movements; and *self-location*, the perception of being spatially situated within that body. This tripartite structure reflects the broader theoretical grounding of embodiment in multisensory integration and predictive coding models of perception.

In line with these frameworks, the congruence between *visuomotor and visuotactile feedback* is essential for inducing strong ownership illusions. A foundational example is the Rubber Hand Illusion (Botvinick & Cohen, 1998), which showed how synchronous tactile stimulation applied to a rubber hand and a participant's hidden hand can create the compelling feeling that the rubber hand is one's own. Similar mechanisms have been replicated in immersive VR (Slater et al., 2010), where congruent multisensory feedback strengthens embodiment and alters bodily self-consciousness.

Agency, while partly integrated into embodiment, has its own theoretical lineage in motor control theories, where it is conceptualized as the sense of authorship over one's actions. This arises from the match between predicted sensory consequences (generated through forward models in the brain) and actual sensory feedback (Jeunet, N'Kaoua, & Lotte, 2016). A disruption in this match reduces agency, while congruence reinforces it. In XR, agency is manipulated by allowing users to directly control avatars or virtual limbs through congruent movements, leading to enhanced immersion and engagement. Research in cognitive neuroscience further suggests that agency is critical not only for motor control but also for higher-level experiences of autonomy, responsibility, and learning.

The educational and psychological implications of embodiment and agency are profound. Studies have shown that embodying avatars of different identities can alter implicit attitudes and social cognition, a phenomenon known as the *Proteus effect* (Banakou, Hanumanthu, & Slater, 2016; Yee & Bailenson, 2007). By embodying avatars with specific characteristics (e.g., different gender, race, or age), individuals exhibit shifts in implicit biases and attitudes, suggesting that XR can foster *perspective-taking* and *empathy*. By embodying avatars with specific characteristics (e.g., different gender, race, or age), individuals exhibit measurable shifts in implicit biases and social attitudes, suggesting that XR can foster perspective-taking and empathy. A seminal study by Peck, Seinfeld, Aglioti, and Slater (2013) showed that embodying White participants in a Black virtual body led to a significant reduction in implicit racial bias, as measured by the Implicit Association Test. Similarly, Banakou, Hanumanthu, and Slater (2016) demonstrated that embodying adults in child-sized avatars altered implicit perceptions of self, increasing identification with childlike attributes. These effects build on earlier work by Yee and Bailenson (2007), who introduced the *Proteus effect*, showing that the attractiveness or perceived professionalism of an avatar can shape both in-world behavior and subsequent real-world interactions. More recently, Maister, Slater, Sanchez-Vives, and Tsakiris (2015) proposed that virtual embodiment can be leveraged to induce long-term changes in intergroup attitudes through mechanisms of body ownership and self-identification with the avatar.

Sense of agency and sense of body ownership are widely acknowledged as core components of XR experiences, as they underpin embodiment, interaction, and the subjective experience of acting within virtual environments. Importantly, these constructs are not unitary phenomena but emerge from multiple interacting processes that operate at different cognitive and sensorimotor levels. A recent systematic review by Girondini et al. (2025) offers a comprehensive overview of how agency and body ownership have been assessed in immersive virtual reality, explicitly distinguishing between implicit and explicit measurement approaches. One of the key contributions of this review is the demonstration that implicit indicators, such as intentional binding, proprioceptive drift, or physiological responses, and explicit self-report measures do not necessarily converge and may lead to partially divergent interpretations of the same XR experience.

This divergence is theoretically meaningful rather than methodological noise. Implicit measures are thought to capture low-level, pre-reflective mechanisms grounded in sensorimotor integration and bodily prediction processes, whereas explicit measures primarily reflect reflective judgments shaped by beliefs, expectations, and contextual interpretation. As a result, XR manipulations may selectively affect one level without producing corresponding changes at the other, revealing a functional dissociation between experiential components of agency and ownership. Recognizing this distinction is crucial, as relying on a single type of measure risks oversimplifying these constructs or misrepresenting the experiential impact of XR technologies (Girondini et al., 2025).

Finally, embodiment and agency intersect with *spatial cognition*, since XR environments rely on orientation, navigation, and memory processes to construct mental representations of space. Classic studies in spatial cognition (Richardson, Montello, & Hegarty, 1999; Waller, Loomis, & Haun, 2004) show how navigation in virtual environments engages the same cognitive and neural mechanisms as navigation in the physical world, influencing wayfinding, memory consolidation, and spatial updating. In this sense, XR does not only provide a stage for embodiment and agency but actively reshapes cognitive maps and spatial knowledge.

Emotion and Motivation

Beyond perceptual and sensorimotor dimensions, XR strongly influences *emotional and motivational processes*, which are central to learning. From the perspective of appraisal theories of emotion (Scherer, 2001), emotions arise from cognitive evaluations of events in relation to personal goals and concerns. Immersive environments, due to their realism, interactivity, and capacity to simulate threat or novelty, can elicit powerful affective reactions ranging from fear to awe (Riva et al., 2007). Chirico and Gaggioli (2019) demonstrated how immersive virtual reality can effectively induce awe experiences by presenting perceptually vast, novel, and highly interactive scenarios, with measurable effects on cognitive flexibility, well-being, and prosocial tendencies. In this sense, VR's capacity to elicit awe and other epistemic emotions does not merely provide intense affective experiences but also contributes to learning, creativity, and the expansion of cognitive schemas (Chirico et al. 2016).

In educational contexts, emotions play a central role in guiding attention, engagement, and learning strategies. According to Pekrun's Control-Value Theory of Achievement Emotions (2006, 2017), *academic emotions* are determined by two core appraisals: perceived control over learning activities and the value attributed to them. Within this framework, epistemic emotions such as curiosity, surprise, and confusion are particularly relevant to XR learning, as they sustain exploration, foster deeper cognitive processing, and drive knowledge construction. XR environments, by presenting novel, interactive, and sometimes uncertain scenarios, are especially effective in stimulating such emotions, thereby enhancing learning outcomes (Pekrun et al., 2017).

Motivation constitutes another fundamental dimension. Drawing on Self-Determination Theory (SDT) (Deci & Ryan, 2012), XR can foster intrinsic motivation by supporting the three basic psychological needs: autonomy (the freedom to explore and make meaningful choices in virtual environments), competence (the opportunity to develop and demonstrate skills through interactive feedback), and relatedness (the sense of connection with others in shared XR spaces). At the same time, XR often integrates gamification elements that provide extrinsic motivation, such as rewards, points, or progress indicators. Experimental studies (e.g., Parong & Mayer, 2018) suggest that gamified XR experiences can significantly enhance motivation and learning, provided that extrinsic incentives do not undermine intrinsic engagement. A complementary construct is affective presence, defined as the contribution of emotions to the subjective sense of "being there" in XR (Riva et al., 2016). Emotions not only amplify the perception of reality in mediated experiences but also strengthen memory encoding and retrieval, increasing long-term learning effectiveness.

Social Interactions

A further key domain is *social interaction*, which is fundamental in collaborative and constructivist approaches to learning. Theories of social presence (Short, Williams, & Christie, 1976; Biocca, Harms, & Burgoon, 2003) explain how XR enables learners to perceive others as "real" and to share experiences within mediated environments. Relatedly, co-presence (Nowak & Biocca, 2003) emphasizes the subjective sense of sharing space and mutual awareness with others. These dimensions of mediated interaction are critical for trust, cooperation, and satisfaction in educational settings (Oh, Bailenson, & Welch, 2018), and align with socio-constructivist theories of learning where collaboration and dialogue are central. Social presence also intersects with self-representation: the previously mentioned Proteus effect (Yee & Bailenson, 2007) demonstrates that avatar characteristics (e.g., attractiveness, professionalism, height) shape behavior in XR and influence subsequent offline interactions, highlighting the profound impact of identity construction in virtual contexts on psychological and social outcomes.

Flow

Flow, a state of deep engagement characterized by concentration, intrinsic motivation, and the balance between challenge and skill (Csikszentmihalyi & Csikszentmihalyi, 1990), is another psychological factor frequently associated with effective XR learning. While some studies (Bruns et al., 2024) have found no significant differences in flow between XR modalities, others highlight its moderating role in improving learners' attitudes and sustained attention, especially when presence is high (Mulders & Träg, 2023). Flow is often induced in XR environments that allow for meaningful interaction, rapid feedback, and goal-directed tasks, conditions which are frequently met in well-designed educational XR applications.

Notably, presence and flow do not operate in isolation but rather interact in a reciprocal and dynamic fashion. A strong sense of presence may act as a precursor to flow by enhancing situational involvement and emotional investment, while flow may deepen the perception of presence by narrowing attentional focus and reducing awareness of external distractions. This interplay creates optimal conditions for deep learning, particularly in disciplines requiring high levels of conceptual engagement or experiential knowledge, such as environmental education, music, and medical training (van Limpt-Broers et al., 2020; Bruns et al., 2024).

Expanding on the traditional notion of individual flow, recent studies have introduced the concept of *networked flow* (Gaggioli et al., 2012; Chirico et al., 2018), which describes the emergence of a shared state of optimal experience within collaborative or technologically mediated contexts. Whereas classical flow theory (Csikszentmihalyi & Csikszentmihalyi, 1990) emphasizes individual absorption in a task, networked flow occurs when multiple participants synchronize their attention, goals, and emotional engagement through reciprocal feedback and mutual attunement. This collective state is characterized by heightened coordination, empathy, and social connectedness, leading to a sense of "acting as one" within a group (Chirico et al., 2018). In XR-based learning environments, such states are facilitated by interactive affordances, for instance, shared virtual spaces, real-time communication, and collaborative problem-solving, that enable participants to co-construct meaning and sustain collective engagement.

Gaggioli et al. (2012) conceptualize networked flow as a socially distributed form of flow supported by digital technologies that mediate both individual and collective experiences. In this framework, the immersive and embodied affordances of XR can strengthen the coupling between cognitive, affective, and social processes, fostering group cohesion and co-presence. This is particularly relevant in educational settings where collaboration and shared creativity are integral to learning outcomes. When presence, flow, and social interaction align, XR environments can promote a distributed form of engagement that extends beyond the individual mind to the interpersonal and systemic dimensions of learning. Such conditions mirror the dynamics of networked flow, in which technology acts as a facilitator of collective awareness, synchronized effort, and emotional resonance among learners (Gaggioli et al., 2012; Chirico et al., 2018).

1.2 XR in Higher Education: Potential and Challenges

1.2.1 Advantages of XR in Higher Education

As highlighted in a recent systematic review by Fernández-Cerero et al. (2024), XR enables immersive and interactive learning experiences that significantly enhance the understanding of complex subjects, foster long-term knowledge retention, and support the personalization of learning pathways in accordance with diverse cognitive styles. Immersive environments do not merely present virtual contents (therefore being useful for simulations, visualization, etc.) but, more importantly, allow students to actively explore, manipulate, and experience abstract phenomena, promoting situated learning and the construction of meaning through experiential engagement (Fernández-Cerero et al., 2024). This aligns with constructivist and experiential learning theories, which emphasize the importance of learner-centered, context-rich environments for deep learning.

Crucially, XR technologies have also been shown to promote cognitive and socio-emotional skills, including critical thinking, collaboration, and problem-solving. According to Crogman et al. (2025), extended reality fosters not only individual comprehension but also collective learning dynamics, offering opportunities for group-based interaction and real-time feedback within shared virtual spaces. These environments stimulate emotional engagement and epistemic curiosity, which are essential for sustained attention and reflective learning. Moreover, XR-based platforms appear particularly well-suited for Generation Y and Z students, whose digital fluency and preference for interactive, multimodal content align closely with the affordances of immersive technologies (Kuleto et al., 2021). In these environments, learners can exercise agency over their learning trajectories, fostering autonomy, intrinsic motivation, and a deeper sense of ownership over their educational experiences.

From a curricular standpoint, XR is especially beneficial in domains requiring spatial reasoning, visual processing, and hands-on skills, such as engineering, medicine, and the natural sciences. As Idrees, Morton & Dabrowski (2022) and Fan & Zhang (2024) demonstrate, the integration of XR into academic programs has led to measurable improvements in learning outcomes, including higher test scores, increased satisfaction, and improved performance in simulation-based activities. These benefits are not limited to technical fields: immersive storytelling, embodied metaphors, and interactive simulations offer valuable pedagogical affordances in the humanities and social sciences as well, supporting empathy-building and the exploration of abstract concepts through experiential means.

Furthermore, XR shows promise in advancing educational inclusion. The adaptability of immersive environments allows for the accommodation of diverse needs and learning profiles, including neurodivergent students, by reducing cognitive overload and allowing for customized pacing and sensory modulation. Instructors have also highlighted XR’s role in expanding access to learning opportunities that might otherwise be constrained by logistical, financial, or ethical considerations, such as dangerous experiments, distant locations, or sensitive case studies (Idrees, Morton & Dabrowski, 2022; Birt et al., 2018). Finally, empirical evidence supports XR’s capacity to elevate learner engagement, often leading to increased motivation, reduced dropout rates, and a more meaningful connection between learners and educational content (Crogman et al., 2025; Young et al., 2020). The collective findings from recent studies suggest that XR can be a pedagogical catalyst capable of reshaping traditional instructional models and addressing several long-standing limitations of higher education.

Beyond these well-documented cognitive and instructional benefits, XR experiences exhibit a distinctive *disruptive* potential in educational contexts, particularly in their capacity to foster divergent thinking and generative forms of learning. By enabling learners to inhabit non-ordinary environments, adopt alternative perspectives, or engage with scenarios that deliberately violate physical, social, or epistemic constraints, XR can interrupt habitual modes of reasoning and encourage the exploration of multiple solution pathways (Riva et al., 2016; Radianti et al., 2020). From an educational perspective, such disruption should be understood not as a drawback but as a pedagogical resource: research on creativity and learning consistently shows that exposure to novelty, uncertainty, and perspective shifting can stimulate epistemic curiosity, cognitive flexibility, and creative problem-solving (Beghetto, 2019; Kaufman & Sternberg, 2010). XR environments can thus function as *safe spaces for experimentation*, where learners are encouraged to test hypotheses, explore alternative representations, and learn from error without the immediate constraints or risks of real-world consequences. This experiential freedom supports divergent thinking by promoting openness, exploratory behavior, and the recombination of knowledge across domains (Riva et al., 2019; Baños et al., 2020). When intentionally designed for educational purposes, XR experiences can therefore move beyond the mere enhancement of existing instructional practices and actively challenge linear, content-driven pedagogies, enabling more reflective, creative, and transformative learning processes (Mezirow, 2000; Riva et al., 2022). Such outcomes are particularly relevant in higher education, where preparing learners to navigate complexity, ambiguity, and innovation has become a central educational goal.

1.2.2 Open Challenges

Despite the transformative potential of XR in higher education, its widespread implementation faces a complex set of pedagogical, technological, and institutional challenges. A key barrier lies in the lack of structured support and guidance for instructors, many of whom struggle to integrate XR tools effectively into their teaching practices (Idrees, Morton & Dabrowski, 2022). This absence of institutional scaffolding is further exacerbated by infrastructural and administrative limitations, such as inadequate access to hardware, insufficient bandwidth, and limited technical expertise (Hawkinson et al., 2024). Furthermore, the cost of XR devices and software remains prohibitive for many institutions, thereby deepening existing digital divides and raising concerns about equitable access (Crogman et al., 2025; Obeidallah, Ahmad & Qutishat, 2023). Students themselves may face usability issues, ranging from technological unfamiliarity to cognitive overload caused by overly complex interfaces or immersive environments (Crogman et al., 2025). The challenges can be thematically grouped into teacher-related issues (e.g., lack of training, resistance to change), student-related concerns (e.g., accessibility, digital literacy), and technology-related obstacles (e.g., limited content, infrastructure, and software compatibility) (Obeidallah, Ahmad & Qutishat, 2023).

Additionally, content creation is often time-consuming and resource-intensive, requiring interdisciplinary collaboration and iterative design processes that are not always feasible within traditional academic settings (See et al., 2023). Despite these significant hurdles, the literature highlights a growing optimism about the potential of XR to reshape teaching and learning, particularly when supported by institutional investment, participatory design practices, and robust frameworks such as the Open XR for Education Framework (OXREF), which promotes open-source, scalable, and pedagogically grounded solutions (Abeywardena, 2023). Ultimately, addressing these challenges requires a coordinated effort from academic leaders, instructional designers, and policymakers to create sustainable ecosystems for XR integration in graduate education.

Among the potential challenges associated with learning in XR, a central issue concerns the management of cognitive demands. According to Cognitive Load Theory (CLT) (Sweller, 2010), three types of cognitive load can be distinguished: intrinsic load, linked to the inherent complexity of the material to be learned; extraneous load, caused by poorly designed instructional features or irrelevant stimuli; and germane load, which refers to the cognitive resources invested in constructing and automating schemas. XR environments, while offering rich and interactive experiences, risk generating excessive extraneous load if they are overly complex, visually cluttered, or provide unnecessary interactional features, thus hindering efficient processing and learning. Conversely, when carefully designed, immersive tasks can reduce extraneous load and maximize germane load, thereby facilitating schema construction and promoting the transfer of knowledge.

Cognitive load represents a key construct for interpreting learning processes in XR-based environments; however, its assessment under ecologically valid conditions remains methodologically challenging. Traditional self-report instruments such as the NASA Task Load Index (NASA-TLX) are widely adopted to measure perceived cognitive load (Hart & Staveland, 1988), yet they are inherently retrospective and episodic, making them unsuitable for continuous or real-time monitoring during immersive learning activities. This limitation is particularly relevant in XR contexts, where cognitive load is not static but dynamically evolves as learners adapt to task demands, interaction modalities, and the virtual environment itself Paas, Renkl & Sweller, 2003; Sweller, 2010). As a result, learning effects may be obscured when early phases of overload decrease over time, unless such fluctuations are explicitly considered.

To address these limitations, recent research has explored a range of psychophysiological methods aimed at approximating continuous assessment of cognitive load. Electroencephalography (EEG) has been extensively investigated, with changes in frontal theta and parietal alpha activity shown to correlate with working memory demands and mental effort during complex tasks, including immersive and three-dimensional learning environments (Antonenko et al., 2010; Khan et al., 2025). Eye-tracking and pupillometry have also emerged as promising non-invasive indicators, as fixation patterns, saccadic behavior, and task-evoked pupillary responses have been shown to reflect variations in cognitive load during VR-based training when controlled for luminance and visual confounds (van der Wel & van Steenbergen, 2018; Lee et al., 2021). Additional studies have combined cardiovascular measures such as heart-rate variability and electrodermal activity with ocular metrics to derive composite workload indicators sensitive to task complexity and attentional demands (Brouwer et al., 2015; Ma et al., 2024).

Despite their potential, these psychophysiological approaches present substantial limitations for use in authentic educational settings. Their interpretation remains indirect and context-dependent, they often require intrusive or technically demanding instrumentation, and their validity as pure indicators of cognitive load, distinct from stress, arousal, or emotional engagement, remains an open issue (Makransky & Petersen, 2019;

Lucchese, 2025). Consequently, their application in real-life XR learning scenarios is still largely experimental. Considering these constraints, the present thesis adopts a design-oriented and preventive approach to cognitive load management, prioritizing instructional strategies aimed at reducing extraneous load through simplified interaction mechanics, clear task structuring, multimodal scaffolding, and progressive onboarding. While continuous monitoring of cognitive load in ecologically valid XR environments remains an important direction for future research, proactively minimizing overload through informed design choices represents a pragmatic and theoretically grounded strategy for ensuring that the educational potential of XR is not masked by excessive cognitive demands.

A further challenge is represented by the role of self-efficacy, defined by Bandura (1997) as an individual's belief in their ability to successfully perform specific tasks. In the context of XR, technological self-efficacy has been shown to significantly influence learners' persistence, engagement, and perceived outcomes (Makransky & Petersen, 2021). Students who feel competent in navigating immersive systems are more resilient when facing difficulties and more likely to achieve positive results, whereas low self-efficacy can amplify frustration and disengagement.

Ultimately, the effectiveness of XR in education must also be evaluated in terms of transfer of learning, understood as the capacity to apply knowledge and skills acquired in virtual environments to real-world contexts (Perkins & Salomon, 1992). Empirical evidence indicates that XR is particularly effective in domains that demand procedural accuracy, spatial reasoning, and embodied practice, including medicine, engineering, and architecture (Mikropoulos & Natsis, 2011; Radianti et al., 2020). This highlights both the opportunities and challenges of XR: when well-designed, immersive environments can integrate emotional engagement, motivational support, social interaction, and cognitive optimization to foster not only knowledge acquisition but also deeper, transformative changes in skills, behaviors, and attitudes.

The present doctoral work seeks to address some of these challenges, particularly those concerning usability, limited technological familiarity, and the management of cognitive load in immersive environments (Crogman et al., 2025; Obeidallah, Ahmad & Qutishat, 2023), as well as sustainability, scalability, and resistance to innovation in the adoption of immersive technologies in higher education (Abeywardena, 2023 Idrees, Morton & Dabrowski, 2022). In response to these issues, as previously defined, the research is structured around four main objectives: (i) to understand the expectations, needs, and concerns of both students and faculty members regarding the integration of XR in higher education; (ii) to develop and test an instructional model for immersive learning, namely the "MetaLab" framework; (iii) to evaluate the impact of immersive experiences on students' cognitive, social, and emotional engagement; and (iv) to provide practical guidelines and co-design tools for educators and instructional designers, in order to support an inclusive, user-centered, and scalable implementation of XR-based learning.

1.3 Empathize Phase: Exploring Faculty Members Perspectives about XR Technology

The first objective is addressed through the *Empathize* phase of the project (Fig. 9), conducted with both students and faculty to capture their perspectives, expectations, and concerns.

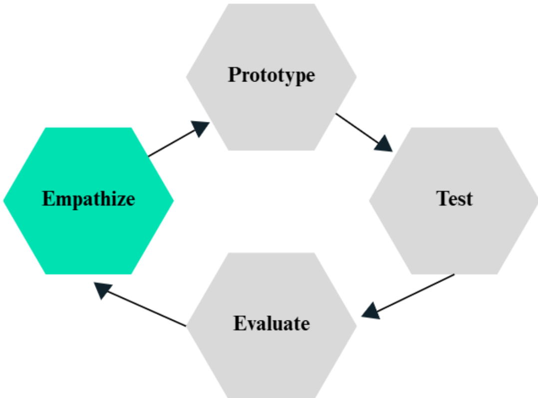


Fig. 9. Current stage of the doctoral process.

This phase provided the empirical basis for the subsequent instructional design process, ensuring that the development of the MetaLab framework was informed by the lived experiences of its key stakeholders. The following section therefore presents the two studies involving faculty members and students.

1.3.1 Rationale and Objectives

To reach the first aim of the present PhD work (i.e., understanding the expectations and concerns of faculty members regarding XR in higher education), a series of Experiential Learning Workshops (ELWs) were conducted with faculty members with a dual rationale. Firstly, they sought to provide them with a direct, hands-on encounter with XR technologies, thereby shifting the narrative from abstract discussion to embodied understanding. This aligns with constructivist perspectives on adult learning, which emphasize the value of experiential engagement in fostering meaningful conceptual change (Kolb, 2014; Schön, 1987). Secondly, the workshops served as a generative platform for collecting feedback, ideas, and critical reflections from participants, an approach consistent with participatory and design-based research traditions (Di Salvo, Clement & Pipek, 2012; Barab & Squire, 2016).

As described by Cronin and Connolly (2007), experiential workshops allow Knowles' (1978) first principle of adult education by providing learners with a safe environment in which to experiment and develop their practice. Indeed, experiential workshops embody two central principles of constructivist educational philosophy: (i) learning is conceived as an active process of constructing rather than passively acquiring knowledge, and (ii) instruction is understood as the facilitation of this construction rather than the transmission of information (Duffy, 1996).

The use of group-based experiential workshops is consistent with constructivist approaches, as they foster collaborative and interdependent forms of self-directed learning (Candy, 1991). Their effectiveness relies on a combination of psychological and social processes. On the individual level, psychological factors such as emotional preparedness and the influence of internalized early experiences can shape learning outcomes (Miller, 1990). On the social level, processes related to group composition, developmental dynamics, and the group's relationship to the broader organizational context significantly affect the realization of learning (Miller, 1990). Experiential groups also support reflection on professional identity and social representations, enabling participants to cultivate more realistic and less stereotypical perspectives of their future roles (Falgares et al., 2017). Overall, the value of experiential learning derives from its emphasis on meaning-making through reflection, which leverages adult learners' prior experiences as catalysts for new knowledge (Lewis & Williams, 1994).

Research has highlighted the methodological advantages of experiential workshops in enhancing participant engagement and generating rich data in user research (Ørngreen & Levinsen, 2017; Bogers et al., 2016). By enabling participants to interact directly with platforms, services, or products of interest, workshops provide opportunities for first-hand experimentation and allow researchers to identify unanticipated factors and insights (Ørngreen & Levinsen, 2017). Their situated, hands-on nature encourages participants to move beyond functional features and to engage with holistic experiences that stimulate the senses, evoke emotions, and inspire new ideas (Hassenzahl, 2018). Moreover, the immersive and collaborative design of workshops facilitates processes of meaning negotiation between researchers and participants, while the integration of gamification elements can further enhance engagement and user experience in research contexts (Deterding et al., 2011; Ørngreen & Levinsen, 2017). Recent work has shown that interactive workshops incorporating storytelling and practical implementation strategies can also promote sustained motivation and knowledge retention among educators beyond the immediate session (Ceneciro, 2025).

Given these findings, and in line with recent literature noting that educators' practical experience with VR/AR/XR technologies remains limited (Schwaiger et al., 2024), the first, qualitative phase, of this PhD project adopted ELWs as a methodological strategy to elicit rich, contextualized, and actionable understandings of XR technologies among faculty members, thereby providing empirically grounded insights to inform the subsequent phases of the research process, including prototyping and implementation. In the following section, the specific procedures adopted to plan and conduct these workshops will be presented in detail, in accordance with guidelines and best practices provided by the relevant literature (Hogan, 2002; Yalom & Leszcz, 2005; Relf & Heath, 2007).

1.3.1.1 Planning Experiential Workshops

The effectiveness of ELWs depends largely on careful planning, as these settings are shaped not only by their educational content but also by the psychological and social conditions under which learning occurs.

Indeed, ELWs for adult learners are most effective when they cultivate a psychologically safe, low-threat climate that supports self-initiated engagement, since attitudes and skills are internalized more readily under conditions of autonomy and emotional security (Rogers, 1969; Deci & Ryan, 2000; Edmondson, 1999). Accordingly, facilitators require dual competence, namely, subject-matter expertise and process skills, to adapt structure, pacing, and activities to heterogeneous learner profiles while containing affect and maintaining task focus (Yalom & Leszcz, 2005).

As Relf and Heath (2007) observe, participants enter experiential groups with distinct personal histories, values, and beliefs; accordingly, facilitators require a nuanced grasp of group dynamics and the psychological processes that shape interaction. Because experiential work can elicit strong affect, its pedagogical value depends on facilitators' capacity to help learners recognise, regulate, and make meaning of their emotional responses. Episodes of distress may unsettle the group, yet, when appropriately contained and debriefed, they can become occasions for substantive learning and for deeper insight into self and others. Throughout, facilitators should remain vigilant to particularly vulnerable participants and, where necessary, arrange individual follow-up outside the session (Relf & Heath, 2007).

A deliberate decision about the degree of structure is central: tightly scaffolded sessions ensure coverage and fidelity, whereas open-agenda formats privilege emergent meaning-making; both can be aligned with the phases of experiential learning (Kolb, 1984). Early norming through co-constructed ground rules clarifies expectations, reduces ambiguity, and supports risk-taking (Tuckman, 1965; Rogers, 1969), while co-facilitation, using pre-negotiated models such as shared leadership, expertise-split, or task/ process splits, distributes cognitive–emotional load, enables in-the-moment support, and models interprofessional collaboration (Hogan, 2002).

Attention to the physical setting (reconfigurable layouts, light/air, humanizing touches) sustains energy and participation, and explicit confidentiality agreements protect trust; anxiety-provoking opening exercises that risk misrepresentation should be avoided. Learning is consolidated through guided, deliberate practice with specific, change-focused feedback, which surfaces "blind spots" and strengthens self-efficacy (Luft & Ingham, 1955; Bandura, 1997; Hattie & Timperley, 2007); robust evidence supports the use of simulations and role-play for improving communication in care contexts (Fallowfield et al., 2002; Gysels et al., 2005).

Optimal group size is typically small (≈6–15), scaling only with additional experienced facilitators, and throughout, the frame remains educational rather than therapeutic: emotion is acknowledged and contained in service of clearly articulated learning outcomes, with facilitators practicing ongoing self-reflection to monitor their own responses and sustain the learning contract (Argyris & Schön, 1997; Yalom & Leszcz, 2005).

Building on this body of literature, the ELWs conducted with faculty members were designed to: (i) create a psychologically safe climate to encourage open participation and self-initiated engagement, (ii) propose sessions able to balance guidance in the exploration of the XR tools and environments with self-exploration, (iii) involve a small-group of faculty members (10-12 maximum at session), to facilitation trust, collaboration, and emotional containment. The physical setting of the sessions was arranged to support participation and create a comfortable atmosphere. Facilitators maintained a clear focus on the learning outcomes while encouraging contributions according to participants' capacities. This design enabled faculty members to engage meaningfully with XR technologies and generated insights to guide subsequent phases of the research. Qualitative methods were used to capture these insights and experiences, reflecting both individual perspectives and group dynamics. The rationale for adopting these methods and their application within the workshops will be detailed in the following section.

1.3.1.2 Qualitative methods in ELW

Within experiential workshops, two complementary qualitative methodologies, observation and reflective practice, offer distinct yet mutually reinforcing contributions to the study of learning processes. Observational methods provide insights into the triggers and mechanisms of interest and engagement, capturing variations in learner responses according to individual characteristics (Renninger & Bachrach, 2015).

Structured observational methods in psychological and educational research often rely on established coding systems designed to capture interactional processes with reliability and comparability. A classic example is Bales's *Interaction Process Analysis* (IPA, 1950), which categorizes small-group behaviour into socio-emotional and task-related acts to map how members contribute to group functioning (Bales, 1950). In educational contexts, Flanders's *Interaction Analysis Categories* (FIAC) provides a systematic approach to analysing classroom discourse by classifying teacher and student verbal behaviours, such as lecturing, questioning, responding, or silence, thereby offering insights into instructional styles and participation patterns (Flanders, 1970). More recent sequential coding approaches extend these frameworks by examining the temporal order of behaviours, identifying probabilistic patterns in how one type of interaction follows another, and thus revealing the dynamic structures underlying group and classroom exchanges (Bakeman & Gottman, 1997). Together, these methodologies exemplify how structured observation can move beyond impressionistic accounts of interaction to produce quantifiable, theory-driven data, supporting both explanatory analysis and comparative evaluation across studies.

Unstructured observation represents a qualitative methodology that privileges openness and flexibility over predetermined coding schemes, allowing researchers to document practices, routines, and meanings as they unfold within the activity system (Gold, 2017; Spradley, 1980; Lincoln & Guba, 1985; Angrosino, 2007; Mulhall, 2003). Unlike structured observation, which applies a priori categories to ensure comparability, unstructured approaches focus on capturing situated contingencies, tacit routines, and emergent behaviours that formalized instruments may overlook. The researcher's role often oscillates along a continuum between *observer-as-participant* and *participant-as-observer*, requiring reflexive attention to positionality and interpretive stance (Spradley, 1980). This flexibility makes unstructured observation particularly valuable for generating "thick descriptions" of social and educational processes, revealing the implicit norms and interactional cues that participants themselves may not articulate. For example, Williamon et al. (2013) employed unstructured participant observation in the context of music education to investigate rehearsal practices in conservatoires. By immersing themselves within rehearsal settings, the researchers were able to document subtle aspects of peer collaboration, nonverbal coordination, and tacit learning routines that would likely have remained inaccessible through structured protocols or self-report methods. Such findings illustrate the methodological strength of unstructured observation in uncovering micro-level dynamics of engagement and meaning making, thereby enriching understanding of experiential learning processes.

Reflective practice (RP) constitutes an interpretive, practitioner-centred methodology in which reflection itself is treated as a form of inquiry into the indeterminate problems of professional life, with the aim of connecting understanding to action (Dewey, 1933; Schön, 2017). In contrast to rational–technical models of problem solving, RP emphasises *reflection-in-action* and *reflection-on-action* as processes through which practitioners interrogate assumptions, generate meaning, and test new responses (Schön, 2017). In both educational and health contexts, RP has been developed as a vehicle for critical and emancipatory learning, enabling individual experiences to be situated within broader organizational, professional, and socio-political frameworks (Rivers, Aggleton, & Whitty, 1998; St Leger, 2001; Issitt, 1999, 2003; Perkins, Simnett, & Wright, 1999). Methodologically, it is commonly operationalized through guided reflective writing and facilitated small-group dialogue, typically in groups of around four participants, with confidentiality agreements, diverse membership to encourage perspective-taking, and structured prompts designed to support systematic examination of practice, collective meaning-making, and the linking of micro-level events to wider professional or institutional issues (Bolton, 2012; Bolton & Delderfield, 2018; Issitt, 1999; Issit, 2003). While critics have raised concerns regarding hindsight bias, limited practitioner skill, and challenges associated with confidentiality (Newman, 1999; Hannigan, 2001; Stark, Stronach, & Cooke, 1999), these risks can be mitigated through clear facilitation, agreed norms, and a praxis-oriented approach that ensures reflection results in tangible changes in practice.

Empirical studies illustrate the value of RP in professional education: for example, MacLeod, Gordon, & Mann (2009) documented how structured reflective groups in medical education supported students in critically analyzing their clinical encounters, enhancing both self-awareness and professional identity formation. In the context of experiential workshops, RP thus complements observational methods by containing emotional responses, surfacing tacit knowledge, and translating experience into actionable plans, thereby strengthening individual competence, fostering collective capability, and generating shareable insights for curriculum and service development (Rivers, Aggleton, & Whitty, 1998; Bolton, 2012; Bolton & Delderfield, 2018; Issitt, 2003; Cronin & Connolly, 2007).

In the present study, the workshops with faculty members specifically utilized unstructured observation and RP, selected for their complementary capacity to capture both behavioral processes and meaning-making dynamics. Unstructured observation was employed during the entire course of the sessions to document practices, routines, and emergent interactions in situ, offering the flexibility to register tacit cues and situated contingencies that structured instruments may overlook. This approach was particularly suited to identifying how participants engaged with XR technologies in real time, allowing the research team to generate rich descriptions of group dynamics and micro-level mechanisms of engagement. Reflective practice, in turn, was integrated at the finals step of the XR experience, to provide participants with a more structured space for critical analysis of their experiences, supporting the articulation of expectations, concerns, and potential applications. By combining observation with reflective practice, the workshops enabled the collection of insights that were both contextually grounded and personally meaningful, thereby ensuring that the data informed not only an understanding of participants' immediate responses but also broader considerations for the sustainable integration of XR in higher education.

1.3.2 Methods

1.3.2.1 Participants

Following the above methodological guidelines, a total of 12 experiential workshops were conducted over the course of one academic year (i.e., 2022/2023) at Università Cattolica del Sacro Cuore. These sessions took place in the "Immersive Classroom", a purpose-built educational facility equipped with immersive technologies (Fig. 10).

Fig. 10. The Immersive Classroom facility at Università Cattolica del Sacro Cuore

Participants were recruited on a voluntary basis via an email invitation disseminated through institutional channels (e.g., official mailing lists and departmental communications). Overall, the initiative engaged 90 university professors and university executives, spanning a diverse cross-section of academic disciplines and departments. This heterogeneity ensured a broad and representative spectrum of faculty perspectives, enabling the Metaversity research team to gather insights from a wide range of pedagogical backgrounds. The participants had little to no prior experience with immersive virtual reality technologies.

1.3.2.2 Workshops Structure

The format for each workshop (lasting 90 minutes approximately) was as follows (Tab.2):

Tab. 2. Workshops structure.

Schedule	Activity Description	Qualitative Methodology Used
15 min	Onboarding: ice-breaking activity, overview of the workshop goals, logistical and safety instructions, short	-

	demographic survey for research purposes, informed consent.	
30 min	Introduction to XR technology and the Metaverse (lecture): accessible explanation of key concepts and educational potential of the Metaverse and XR technology.	-
5 min	Q&A	-
5 min	Break	-
10 min	Setup and control training: instructions on how to use the headset and controllers in the testing environment.	Unstructured observation
30 min	Experience in the EngageVR Metaverse, divided as follows: 1. Creation of the personal avatar (5 min) 2. Virtual room access (2 min) 3. First steps in EngageVR (3 min) 4. Guided exploration of three different EngageVR environments (20 min)	Unstructured observation and Reflective Practice
10 min	Break	-
20 min	Final Debriefing: focus group/discussion on the potential and challenges of immersive learning; scenario analysis	Guided Discussion

The platform selected for the workshop was *EngageVR*, a professional-grade virtual reality platform designed specifically for education, training, and collaborative events. Unlike entertainment-oriented VR applications, EngageVR provides an enterprise-level environment that supports synchronous multi-user interaction, customizable avatars, and a wide range of virtual settings that can be adapted to diverse pedagogical purposes. The platform enables facilitators to design structured learning experiences, combining traditional teaching formats, such as virtual lecture halls, with more exploratory and immersive environments, such as a library in Oxford, the Moon etc., that promote engagement through storytelling, interactivity, and simulation. EngageVR was chosen for its versatility, accessibility, and pedagogical orientation, as it allows both replication of conventional classroom settings and the extension of learning into imaginative contexts, thereby demonstrating the breadth of possible applications of XR in higher education.

During the immersive phase of the workshop, participants were equipped with head-mounted displays (i.e., Oculus Meta Quest 3) and guided through a curated sequence of virtual environments, each intentionally selected to demonstrate key functionalities of the XR platform. At the outset, participants were asked to create their own avatar and to access an initial virtual room, which served as a starting point for orientation and basic interaction within the environment. The experience was structured around a narrative thread, facilitated by a facilitator (SB) represented as an avatar in the virtual setting, who introduced and illustrated core psychological and pedagogical features of immersive learning, such as spatial immersion, embodiment, environmental interactivity, and the capacity to simulate complex scenarios in a safe and controlled context.

The narrative sequence (Fig. 11) of the workshop commenced in a virtual lecture hall, selected as a familiar environment to demonstrate how XR technologies can replicate and extend traditional teaching practices. Within this space, participants were introduced to conventional instructional tools available in virtual reality, including the use of whiteboards, slide projection, and 3D pens, thereby illustrating the potential of VR to reproduce classroom-based pedagogical activities. At the same time, the session underscored that the affordances of VR extend beyond such replication, offering access to environments that surpass the constraints of physical settings.

To exemplify this potential, participants were teleported from the lecture hall to the surface of Mars, an environment selected to highlight the capacity of XR to simulate diverse and otherwise inaccessible contexts. In this setting, the instructional narrative continued through the presentation of models depicting the landing of a rover and its procedures for soil analysis. A three-dimensional model of the rover was generated in the virtual environment, allowing participants to interact with it and to observe a simulation of the sampling process.

The journey then continued with teleportation to an ocean environment, further illustrating the possibility of designing educational activities that expand not only in terms of content but also across different spatial contexts. Here, participants were given the opportunity to generate three-dimensional elements and modify them directly within the environment, experiencing how XR can combine immersive settings with interactive content creation.

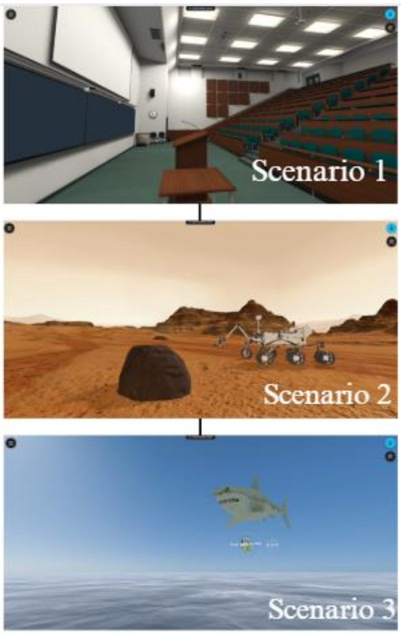


Fig. 11. Sequence of the immersive learning scenarios (i.e., Lecture Hall, Mars Surface, Ocean) visited during the workshops with faculty members.

The methodological rationale behind the choice of these environments draws on evidence that effective immersive learning benefits from a progressive sequence of activities, beginning with familiar contexts to reduce cognitive load and foster orientation, and gradually moving toward more complex or imaginative scenarios that stimulate engagement and exploration (Makransky & Petersen, 2021; Radianti et al., 2020). Furthermore, the use of varied and thematically rich environments reflects the principles of experiential learning, which emphasize the value of contextual diversity and hands-on interaction in supporting meaning-making and knowledge transfer (Kolb, 2014; Dede, 2009). Importantly, such immersive and diverse contexts are also capable of eliciting epistemic emotions, such as curiosity, surprise, and wonder, which play a central role in stimulating inquiry, sustaining engagement, and deepening cognitive processing (Pekrun, 2017; D'Mello et al., 2014). By alternating between familiar educational settings and extraordinary exploratory scenarios, the workshops aimed at providing faculty members the opportunity to reflect on the possibility to both replicate traditional pedagogy and design contextually rich and alternative learning experiences.

Throughout the entire length of the workshops, data was collected through unstructured observation, with facilitators documenting participants' behaviors, interactions, and responses as they unfolded in real time. This approach allowed the research team to capture situated contingencies, emergent practices, and tacit dynamics that may not have been accessible through structured protocols or self-report, thereby generating rich descriptions of how faculty members engaged with XR environments. In the ocean setting, the observational approach was complemented by RP: participants were invited to collectively discuss their experiences, articulate their perceptions of the affordances and challenges of the technology, and link these impressions to their professional teaching contexts. This combination of unstructured observation and reflective practice not only provided an external record of behaviors and group processes but also elicited participants' subjective interpretations and meaning making. Integrating these two methods enabled a more comprehensive understanding of the learning dynamics at play, offering both behavioral and experiential insights to inform the subsequent phases of the research. Finally, during the closing debriefing session, conducted after participants had removed the headset, space was provided for open discussion of their impressions, focusing on the perceived advantages and disadvantages of adopting XR technologies in university teaching.

At the conclusion of the workshop, participants received a follow-up email thanking them for their involvement and providing a link to an online feedback form. The form was designed to collect further reflections on the experience, as well as suggestions for improvement, thereby complementing the data gathered during the sessions. In addition, the email invited educators to indicate their interest in taking part in the successive phase of the project (i.e., *Prototype*), to actually implement an immersive learning experience in their courses.

1.3.2.3 Data Collection and Analysis

Data from the workshops were documented and analyzed through a combination of unstructured observation and reflective practice. During the sessions, facilitators took field notes directly on a computer, adopting an open and flexible approach characteristic of unstructured observation, which privileges thick description over rigid coding (Spradley, 1980; Lincoln & Guba, 1985; Mulhall, 2003). Notes included detailed accounts of participants' actions, verbal exchanges, nonverbal behaviors, and modes of interaction with the XR environments, as well as contextual elements such as timing, room dynamics, and unexpected events.

Reflexive annotations were also added to capture the researchers' positionality and potential influence on the group process, in line with recommendations for reflexive qualitative inquiry (Angrosino, 2007; Gold, 2017). These notes were later reviewed to identify recurring patterns, situated contingencies, and tacit routines, generating "thick descriptions" (Geertz, 1973) that provided a holistic account of engagement and meaning-making processes.

Reflective practice further enriched the dataset: during facilitated debriefings, participants articulated their impressions and interpretations, which were documented through ethnographic notes and, where consent was given, audio recordings. This approach is consistent with reflective methodologies that position reflection as a form of inquiry into professional practice, linking individual experience to broader pedagogical and organizational contexts (Dewey, 1933; Schön, 1983; Bolton, 2012; Bolton & Delderfield, 2018).

The combination of external observations and participants' self-reflections enabled methodological triangulation (Patton, 2014), ensuring that insights were grounded both in observed behaviors and in the meanings ascribed to them by educators. The analysis proceeded through iterative coding, moving from descriptive categorization of observed phenomena to the identification of thematic insights, a process consistent with grounded and interpretive approaches to qualitative analysis (Lincoln & Guba, 1985; Charmaz, 2006).

1.3.2.4 Key Insights

Across the workshops, participants generally displayed a rapid adaptation to the use of XR technologies, demonstrating curiosity and openness during the onboarding phase. Although most had little prior experience with immersive systems, they quickly acquired the basic operational skills required to navigate the environment, such as creating avatars, moving within virtual spaces, and interacting with digital objects. This ease of appropriation is consistent with research suggesting that intuitive interfaces and embodied interaction lower the entry barriers to immersive learning, allowing even novice users to develop a sense of control and confidence after relatively brief exposure (Radianti et al., 2020; Makransky & Petersen, 2021).

Nevertheless, a minority of participants (approximately 10–15% of the total sample, i.e., 8–12 faculty members) experienced initial difficulties in familiarizing themselves with the headsets or managing the basic controls. In these cases, the role of the facilitators proved crucial: by providing step-by-step guidance, troubleshooting, and reassurance, they helped participants gradually overcome discomfort and successfully continue with the activities. Such dynamics underline the importance of scaffolding and facilitation in immersive learning contexts, where technical barriers can temporarily hinder engagement but can be mitigated through targeted support (Dede, 2009; Fowler, 2015).

At the same time, it should be acknowledged that the group of participants represented a self-selected sample of faculty, characterized by a pre-existing interest in innovation and a greater openness toward technological experimentation. This predisposition likely contributed to the overall positive reception and relatively smooth adaptation to the immersive tools, and it should be considered when interpreting the findings and their generalizability. During the sessions, most participants showed clear signs of engagement and enjoyment, including active exploration of the environments, collaborative gestures (e.g., assisting peers with option selection), and verbal expressions of curiosity or surprise when encountering novel scenarios such as the surface of Mars. These reactions align with research on epistemic emotions, which highlight curiosity, wonder, and surprise as important drivers of inquiry and deeper cognitive elaboration (Pekrun, 2017; D'Mello et al., 2014).

Beyond the technical learning curve, the workshops also highlighted broader pedagogical themes. Faculty emphasized that the value of immersive learning lies not simply in exposure to novel environments, but in its potential to foster emotional engagement, and creative collaboration. Emotional engagement was seen as central, since immersive contexts elicited strong affective responses that, if appropriately supported, could sustain motivation and deepen learning (Pekrun, 2006). Finally, the collaborative dimension emerged as a crucial aspect: XR was not only perceived as a tool for individual exploration but also as a catalyst for shared creativity, dialogue, and co-construction of meaning (Sawyer, 2017). The gradual progression from familiar environments (i.e., the virtual lecture hall) to more imaginative scenarios (i.e., Martian surface and the ocean) facilitated an increase in participants' confidence and willingness to experiment, reflecting evidence that structured sequencing of immersive activities supports learning by balancing cognitive load, engagement, and the collaborative creation of knowledge (Makransky & Petersen, 2021).

In the debriefing sessions, key insights emerged (*see* Tab. 3) revealing both the perceived potential of these tools in university curricula and the potential challenges. A central theme that emerged was the capacity of XR to *simulate complex, interactive learning environments*. Participants emphasized how XR allows students to engage in scenarios that would otherwise be difficult, or even impossible, to reproduce in a traditional classroom. This includes simulations that require high levels of interactivity, immersion in alternative realities, or manipulation of virtual elements that mimic real-world systems. Moreover, XR was praised for its ability to *transcend spatial and temporal constraints*, offering learners the opportunity to participate in educational experiences regardless of their physical location. This characteristic was seen as particularly valuable in the context of remote and hybrid learning, where continuity and equity of access remain major concerns. Another widely recognized benefit concerns the translation of abstract or theoretical content into *concrete, experiential forms*. Faculty members noted that XR environments can facilitate deeper understanding by transforming complex ideas into visually and spatially grounded experiences. This not only enhances conceptual clarity but also promotes emotional engagement and cognitive retention. The workshops also highlighted XR's potential to foster *remote collaboration*. Several educators reported positive experiences in using XR platforms to enable group work among geographically dispersed participants. These collaborative dynamics were considered essential in a world where digital co-presence is increasingly central to education.

In parallel, the *gamification of learning* emerged as a motivating factor. By incorporating game-like elements, XR environments were perceived as more engaging and enjoyable, encouraging active participation. Participants believed that this could increase intrinsic motivation and make learning more memorable.

Finally, the workshops served as a space for reflection on the future of education. The hands-on nature of the XR experiences encouraged participants to imagine new pedagogical possibilities and rethink traditional approaches. Many educators expressed interest in continuing to explore XR to innovate curricula and respond to the evolving expectations of students.

Despite the enthusiasm, several critical issues were raised, underscoring the need for thoughtful design and policy strategies to ensure the sustainable and inclusive use of XR in higher education. One recurrent concern was the *limited ergonomics* of immersive devices. Participants described VR headsets and controllers as physically uncomfortable during extended use, potentially hindering attention, immersion, and accessibility. This aspect was seen as a major obstacle, particularly for longer learning sessions. Concerns about *inclusivity and accessibility* also were highlighted, with participants emphasizing that XR technologies must be designed to accommodate diverse physical and cognitive needs. Without careful attention to these aspects, XR risks reinforcing existing inequalities rather than bridging them. From a technological standpoint, the *suboptimal realism* of graphics and avatars, along with restricted interactivity with virtual objects, were seen as limitations that can affect the authenticity and educational impact of the XR experience. These limitations may diminish the perceived credibility of the learning environment and constrain its pedagogical value. Furthermore, many educators pointed to a *scarcity of XR-ready educational content*, noting that most available experiences are not sufficiently tailored to specific academic disciplines. Combined with the high costs of content development and infrastructure, this lack of domain-specific material represents a significant barrier to large-scale implementation. Lastly, participants highlighted *logistical and integration challenges*. The adoption of XR often requires changes to curricula, teaching practices, and institutional support systems. Without clear strategies for integration, the risk is that XR remains a peripheral or novelty element, rather than a core pedagogical tool.

Tab. 3. Summary of perceived benefits and challenges of XR integration in higher education.

Category	Perceived Benefits	Identified Challenges
Learning Experience	- Simulation of complex and interactive scenarios - Transformation of abstract concepts into concrete experiences	- Suboptimal graphic realism - Limited interactivity with virtual objects
Spatial and Temporal Access	- Overcoming physical and temporal barriers - Remote access to educational experiences	- Inclusivity and accessibility barriers for students with specific needs

Collaboration and Participation	- Facilitation of remote group work - Support for collaborative dynamics in distributed environments	- Integration issues with existing educational frameworks
Engagement and Motivation	- Gamification of learning processes: more engaging, interactive, and memorable experiences	- Physical discomfort due to poor ergonomics of headsets and controllers
Educational Innovation	- Encouragement to reflect on the future of education - Experimentation with new teaching models	- Lack of educational content specifically designed for XR - High development and implementation costs
Sustainability and Scalability	- Long term interest in broader and more innovative XR use	- Logistical and infrastructural challenges for stable integration of XR technologies in academic institutions

1.3.2.5 Discussion

The hands-on nature of the workshops, coupled with opportunities for critical reflection, appeared to foster not only awareness of XR's affordances and constraints but also a sense of pedagogical curiosity and commitment to innovation. Majority of participants expressed a strong willingness to continue exploring the educational potential of immersive technologies. Several faculty members declared their interest in joining the second phase of the Metaversity project, aiming to experiment with XR integration directly within their courses. In parallel, others expressed a desire to remain involved as external observers, wishing to monitor the project's progress and assess its impact over time before considering more active participation.

This orientation suggests that direct experiential exposure, when combined with structured dialogue and support, can effectively catalyze a shift from initial skepticism to informed engagement. It also highlights the importance of designing participatory interventions that go beyond technical training to create reflective and co-constructive spaces for academic innovation. Ultimately, the workshops served not only as a site of evaluation but also as a springboard for institutional change, initiating a broader conversation about the future of teaching in immersive environments.

In line with the methodological principles that guided the current doctoral project, namely, Design-Based Research (Brown, 1992; Design-Based Research Collective, 2003; Barab & Squire, 2016; Wang & Hannafin, 2005) and Design Thinking (Brown, 2008; Razzouk & Shute, 2012; Liedtka, 2018), this early *Emphasize* phase ensured that by incorporating faculty perspectives, the research process gained greater ecological validity (Anderson & Shattuck, 2012). This stakeholder-centered approach also reduced the risk of adopting solutionist perspectives detached from real educational practice (Beckman & Barry, 2007; Liedtka, 2018). Importantly, the involvement of stakeholders was not limited to faculty members: a parallel stream of research was conducted with university students, whose perspectives on XR in higher education will be discussed in the following section.

1.4 Empathize Phase: Exploring Student's Acceptance and Use Intention of XR Technology

In parallel with the initial phase of *Empathizing* with faculty members, a complementary study was conducted with university students to explore their expectations and needs regarding the integration of XR technologies in higher education. This investigation sought to capture the student perspective on potential opportunities and challenges, providing a more comprehensive understanding of how XR technologies might be meaningfully embedded within academic contexts. The outcomes of this work have been reported in a scientific publication[9].

1.4.1 Theoretical Background and Rationale

The sustainable and meaningful integration of XR in higher education requires attention not only to institutional readiness and didactic innovation but also to the perspectives of students, who represent the primary end-users of these technologies. Their expectations, perceptions, and willingness to engage are decisive factors in determining whether XR becomes a transient experiment or a lasting component of the academic experience. As highlighted in prior research, adoption and continuance are more likely when technological affordances align with user expectations and lived experiences (Venkatesh et al., 2012; Lee, Hsieh, & Hsu, 2011). Given that XR introduces novel forms of interaction, embodiment, and engagement that often differ markedly from students' previous learning experiences, understanding how learners anticipate these affordances, and how they evaluate them after direct exposure, is critical for designing interventions that are both pedagogically sound and learner centered.

To address this issue, the present study employed the Extended Expectation-Confirmation Model (EECM; Gupta, Yousaf & Mishra, 2020) as its theoretical and methodological framework (Fig. 12). The EECM builds upon the Expectation-Confirmation Model (ECM; Bhattacherjee, 2001) by integrating post-adoption constructs such as confirmation, perceived usefulness, satisfaction, and self-efficacy with pre-adoption factors from the Unified Theory of Acceptance and Use of Technology (UTAUT; Venkatesh et al., 2003), namely performance expectancy and effort expectancy. In this way, the model captures both anticipatory beliefs and post-experience evaluations, offering a comprehensive framework for understanding continuance intention in technology use. This integrative perspective is particularly relevant in the case of immersive technologies, where direct, embodied experience can substantially reshape initial assumptions.

[9] Di Natale, A. F., Bartolotta, S., Gaggioli, A., Riva, G., & Villani, D. (2024). Exploring students' acceptance and continuance intention in using immersive virtual reality and metaverse integrated learning environments: The case of an Italian university course. *Education and Information Technologies*, *29*(12), 14749-14768.

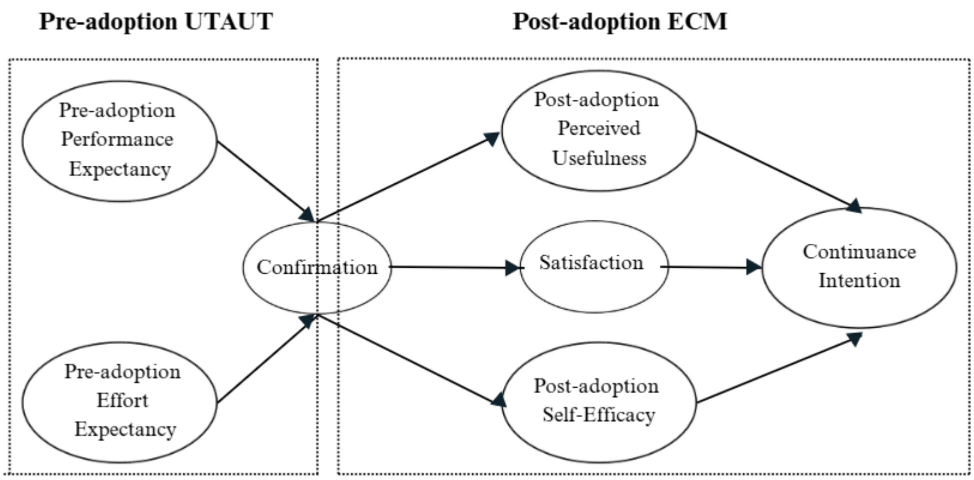


Fig. 12. Theoretical model used in the study adapted from Gupta, Yousaf & Mishra (2020).

The study was conducted with a group of 28 university students enrolled in a five-week elective psychology module designed to provide structured exposure to immersive XR applications. The module included both theoretical lectures and hands-on activities with tools such as social VR platforms, body swap techniques, and relaxation scenarios, thereby allowing students to explore a variety of use cases. Adopting a longitudinal design, data were collected at two time points: before the module (pre-test), to capture students' expectations regarding perceived usefulness and ease of use, and after its completion (post-test), to evaluate their satisfaction, confirmation of expectations, perceived value, self-efficacy, and continuance intention.

The study was guided by four main objectives: (i) to assess students' initial expectations of XR technologies in academic contexts; (ii) to evaluate post-use perceptions, focusing on satisfaction, confirmation of expectations, perceived value, and continuance intention; (iii) to analyze the predictive relationships between pre- and post-use variables within the EECM framework; and (iv) to derive pedagogical and design implications to inform the development of XR-based learning experiences that align with student needs and foster long-term engagement.

By pursuing these objectives, the study contributes to a more comprehensive understanding of the adoption process of XR in higher education, with particular attention to the student perspective. This inquiry complements the institutional and faculty-focused investigations conducted in parallel, thereby offering an integrated perspective on readiness, acceptance, and innovation in immersive learning environments.

1.4.2 Hypotheses

Drawing on prior literature in technology acceptance and continuance models (Bhattacherjee, 2001; Venkatesh et al., 2012), the hypotheses formulated in this study reflect the sequential logic of the Extended Expectation-Confirmation Model.

In the pre-adoption stage, it was expected that students' initial beliefs regarding the usefulness and ease of use of XR technologies would influence the extent to which their experiences later confirmed these expectations. Moving into the post-adoption stage, the model predicts that confirmation plays a central role in shaping students' evaluations of the learning experience, particularly in terms of perceived usefulness, satisfaction, and self-efficacy. Finally, at the continuance stage, these post-adoption evaluations are hypothesized to determine students' willingness to continue using XR technologies in future academic contexts. Taken together, the hypotheses outline a progressive process in which anticipatory beliefs are validated or challenged through experience, shaping subsequent evaluations and ultimately influencing the likelihood of sustained engagement with XR in higher education.

1.4.3 Methods

1.4.3.1 Participants

The study was conducted with 28 psychology students enrolled in a five-week elective module (Tab. 4) designed to provide hands-on exposure to immersive virtual reality (IVR). Of these, 25 students (F = 19; *M*age = 23.4, *SD*age = 1.76) completed both pre- and post-intervention surveys, forming the final sample. While 60% of participants had some prior experience with IVR, 40% reported no previous use. Ethical approval was obtained from the Ethics Committee of the Department of Psychology at Università Cattolica del Sacro Cuore, Milan.

The module combined theoretical lectures with practical sessions in which students directly engaged with IVR applications, including social VR, body swap techniques, relaxation and metaphoric environments, and collaborative simulations.

Tab. 4. Weekly overview of lesson content and IVR activities included in the five-week psychology module.

	Theoretical part	**Practical part**
Lecture 1	Historical overviews about immersive technologies as well as the potential applications of these tools in various fields, including design, education, and healthcare promotion.	Students had practical experience of social VR by using the Metaverse application AltSpaceVR (accessed with an Oculus Quest 2) and making a gamified collaborative experience.
Lecture 2	Students learnt about the body swap technique, an experimental method that involves individuals temporarily experiencing the perspective or sensations of another person typically used for therapeutic interventions.	Students had practical experience of the body swap technique by using an application developed with Unity (accessed with an Oculus Rift) and experiencing being embodied in another person body.
Lecture 3	Students were presented with topics related to relaxation techniques typically used to reduce stress, anxiety, and tension and promote a state of calm and relaxation.	Students had practical experience of relaxation techniques by using an application developed by Become (accessed with an Oculus Quest 2) and experiencing the scenario called "The Secret Garden" (Riva et al., 2020).

Lecture 4	Students were presented with topics related to metaphoric IVR typically used in company settings to support personal growth and self-development.	Students had practical experience of metaphoric virtual environments by using the Become application (accessed with an Oculus Quest 2) and experiencing the scenarios called "The River and the Leaf" and "The Backpack and the Mountain".
Lecture 5	Students were able to evaluate IVR application for individual well-being promotion. They started thinking about their team projects which present new ideas for applications in one of the fields presented so far.	Students had practical experience of other social VR is by using the Metaverse applications Remio and RecRoom (accessed with an Oculus Quest 2).

1.4.3.2 Measures

Data was collected at two time-points: before the module (T0) and after its completion (T1). Pre-adoption measures assessed performance expectancy and effort expectancy (Teng et al., 2022), while post-adoption measures captured confirmation, perceived usefulness, satisfaction, self-efficacy, and continuance intention (Gupta, Yousaf & Mishra, 2020; Lee & Hwang, 2022). All constructs were measured with validated scales on a 7-point Likert format, showing high internal consistency (α = .79–.97). A complete list of the items used for each construct, including the Italian-adapted versions, is provided in Appendix I.

1.4.3.3 Procedure

At the start of the course, participants were fully briefed on the study's aims, ethical safeguards, and data protection procedures, after which they provided informed consent and completed a baseline survey (T0) assessing pre-adoption attitudes toward IVR. At the end of the five-week module, a follow-up survey (T1) was administered to capture post-adoption perceptions, satisfaction, and continuance intention. This two-phase design enabled direct comparison between students' expectations and their evaluations after sustained engagement with IVR. The overview of the procedural timeline is illustrated in Fig. 13.

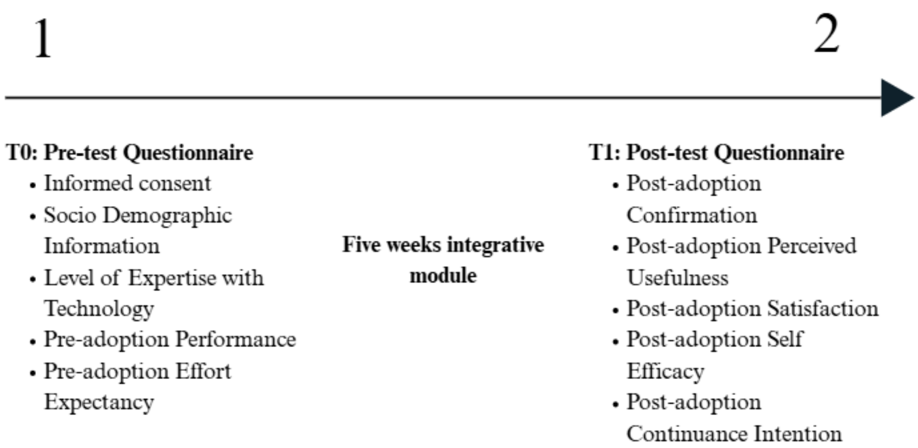


Fig. 13. Overview of the two-phase experimental procedure used in the study.

1.4.3.4 Data Analysis

Descriptive statistics (means and standard deviations) were first computed to summarize the variables, followed by Pearson correlations to examine associations among pre-adoption and post-adoption attitudes, confirmation, and continuance intention. To test the hypothesized relationships within the EECM framework, separate regression models were conducted for each path. Specifically, the study examined whether: (i) pre-adoption performance and effort expectancy predicted confirmation; (ii) confirmation influenced post-adoption perceived usefulness, satisfaction, and self-efficacy; and whether (iii) these post-adoption evaluations predicted students' continuance intention to use XR in academic contexts.

1.4.3.5 Results

Pearson correlation analyses (Tab. 5) were conducted to examine the relationships among the key variables within the EECM framework. Results showed that no significant correlations emerged between pre-adoption constructs and confirmation. Specifically, neither pre-adoption performance expectancy nor effort expectancy were significantly associated with confirmation. These findings suggest that students' initial beliefs about the usefulness and ease of use of IVR did not reliably predict whether their expectations would be confirmed after direct experience.

Conversely, confirmation exhibited strong and statistically significant correlations with all three post-adoption variables. Confirmation was strongly associated with post-adoption perceived usefulness ($r = .89$, $p < .001$); strongly associated with satisfaction ($r = .85$, $p < .001$) and moderately associated with self-efficacy ($r = .59$, $p < .01$).

These results indicate that the extent to which students' actual experiences with IVR aligned with their expectations played a critical role in shaping their perceptions of the technology's usefulness, their overall satisfaction with the learning experience, and their confidence in using it.

Furthermore, correlations between post-adoption variables and continuance intention were also significant and robust. Specifically: post-adoption perceived usefulness was strongly correlated with continuance intention ($r = .83$, $p < .001$); satisfaction was also strongly correlated with continuance intention ($r = .85$, $p <$

.001), and self-efficacy demonstrated a strong positive correlation with continuance intention (r = .76, p < .001). In addition, all post-adoption constructs were significantly associated with continuance intention: perceived usefulness (r = .83, p < .001), satisfaction (r = .85, p < .001), and self-efficacy (r = .76, p < .001).

Tab. 5. The table presents the bivariate Pearson correlations among the main constructs examined in the study.

Variable	M	SD	1	2	3	4	5	6	7
1. Perceived usefulness (pre)	5.54	0.89	—						
2. Perceived ease of use	5.31	0.85	.30	—					
3. Confirmation expectancy	5.06	1.27	.14	−.13	—				
4. Perceived usefulness (post)	4.96	1.45	.18	.16	.89***	—			
5. Satisfaction	5.53	1.60	.17	.10	.85***	.85***	—		
6. Self-efficacy	4.94	1.40	.00	.13	.59**	.61**	.84***	—	
7. Continuance intention	4.93	1.54	.27	−.06	.82***	.82***	.85***	.75***	—

Note. **p < .05, **p< .01, ***p< .001.*

Regression analyses (Tab. 6) provided further support for the hypothesized relationships outlined in the EECM. First, confirmation emerged as a significant and strong predictor of all three post-adoption variables. Specifically: confirmation significantly predicted post-adoption perceived usefulness with a standardized coefficient of β = 1.01, t = 9.02, p < .001; it also significantly predicted satisfaction, with β = 1.06, t = 7.42, p < .001; finally, confirmation was a significant predictor of post-adoption self-efficacy, with β = 0.64, t = 3.42, p < .01.

Moreover, all three post-adoption constructs significantly influenced students' continuance intention: perceived usefulness was a strong positive predictor of continuance intention (β = 0.88, t = 7.09, p < .001); satisfaction also significantly predicted continuance intention (β = 0.82, t = 7.68, p < .001); similarly, self-efficacy had a strong and significant effect on continuance intention (β = 0.83, t = 5.44, p < .001).

Tab. 6. Results of regression analysis testing the hypotheses of the EECM.

PREDICTOR	OUTCOME	B	SE	T

Confirmation expectancy	*Perceived usefulness post*	1.02	0.11	9.16***
	Satisfaction	1.06	0.14	7.58***
	Self-efficacy	0.65	0.18	3.50**
Perceived usefulness post	*Continuance intention*	0.86	0.13	6.83***
Satisfaction	*Continuance intention*	0.93	0.12	7.84***
Self-efficacy	*Continuance intention*	0.83	0.15	5.50***

Note. *$p < .05$, ** $p < .01$, *** $p < .001$.

Although the study did not find empirical support for the influence of pre-adoption factors on confirmation, the results strongly validated the central role of confirmation in shaping post-adoption outcomes. Furthermore, the findings offered robust evidence for the significant predictive power of post-adoption variables, namely, perceived usefulness, satisfaction, and self-efficacy, on students' intention to continue using IVR in educational settings.

1.4.3.6 Discussion

The integration of IVR into higher education represents a rapidly developing field, making it crucial to understand the factors that shape students' acceptance and sustained engagement. This study addressed this issue by applying the Extended Expectation-Confirmation Model (EECM; Gupta, Yousaf & Mishra, 2020) within the context of a five-week university module that incorporated diverse IVR applications in psychology. The model, which connects pre-adoption expectations with post-adoption experiences, offered a useful framework for examining how students' attitudes evolved before and after exposure to immersive technologies.

Contrary to expectations, the findings did not reveal significant relationships between pre-adoption constructs (performance and effort expectancy) and confirmation, diverging from previous studies that reported such effects (Barrett, Pack & Quaid, 2021; Shen et al., 2019; Al-Adwan et al., 2023; İbili et al., 2023). This discrepancy may be explained by contextual factors, including the voluntary nature of enrollment in the elective module, which may have attracted students already positively predisposed toward IVR, and their prior exposure to digital or immersive tools within the broader curriculum, which could have stabilized initial expectations and reduced variability.

In line with the second segment of the EECM, confirmation emerged as a strong predictor of perceived usefulness, satisfaction, and self-efficacy, supporting evidence from previous research in educational technology (Dai et al., 2020; Persada et al., 2021; Rabaa'i et al., 2021). These findings reinforce the importance of experiential alignment, the extent to which actual use meets prior expectations, in shaping students' post-adoption evaluations. Furthermore, all three post-adoption constructs significantly predicted continuance intention, indicating that when learners perceive IVR as useful, satisfying, and manageable, they are more likely to continue engaging with it in future academic contexts.

Overall, the study highlights the central role of experiential congruence in technology-mediated learning. When expectations are met through direct use, students are more likely to acknowledge the pedagogical value of IVR, feel satisfied with the experience, and develop confidence in using it. These conditions are critical to fostering sustained engagement and to ensuring that IVR is adopted as a lasting element of educational practice rather than a transient innovation.

1.5 Implications for XR Implementation in Higher Education

This study offered a longitudinal investigation of students' adoption and continued use of immersive technologies, focusing on IVR and Metaverse platforms within a university course. IVR provided individualized immersive experiences through head-mounted displays, while the Metaverse enabled collaborative, multi-user interactions, allowing students to engage with both learning modalities (*see* "1.1.3 Education 4.0: XR Technologies and Principles" paragraph for details about these technologies).

The results did not show significant effects of pre-adoption beliefs on expectation confirmation, but they underscored the important role of confirmation in shaping post-adoption outcomes, including perceived usefulness, satisfaction, and self-efficacy, which in turn strongly predicted continuance intention. By applying the EECM (Gupta, Yousaf & Mishra, 2020) to the relatively underexplored field of immersive education, the study highlighted the importance of experiential congruence in fostering sustained engagement with IVR and Metaverse technologies. These findings also provide actionable insights for higher education institutions, emphasizing the value of assessing baseline expectations, tailoring instructional design to varying levels of technological familiarity, and ensuring alignment between anticipated and actual experiences.

Within the broader trajectory of this doctoral project, this study represents a key outcome of the *Empathize* phase, as it directly incorporated students' perspectives of XR technologies. By examining how expectations, experiences, and evaluations evolved over time, it provided crucial insights into the psychological and experiential dynamics that underpin technology adoption in higher education. These insights laid the foundation for the subsequent *Prototype* phase.

The key insight captured during the first phase of the project by both faculty members and students served as a basis for creating the MetaLab instructional design model. The *Prototype* phase that will be presented in the following chapter, marks a transition from understanding user needs to concretely address them. The progression from *Empathize* to *Prototype*, given the DBR and design Thinking methodology used in this work, ensures that the solutions developed are not only innovative but also responsive to the authentic needs identified in the initial phase.

2. Prototype Phase: the MetaLab Model and the MetaLabs

The first phase of the doctoral project (i.e., *Empahize*) generated insights that informed the development of the MetaLab model, an Instructional Design framework for immersive education aligned with the expectations, needs, and constraints of both faculty and student. In the *Prototype* phase (Fig. 14), faculty members have been involved in a co-design to generate immersive modules integrated in university curricula, namely the "MetaLabs".

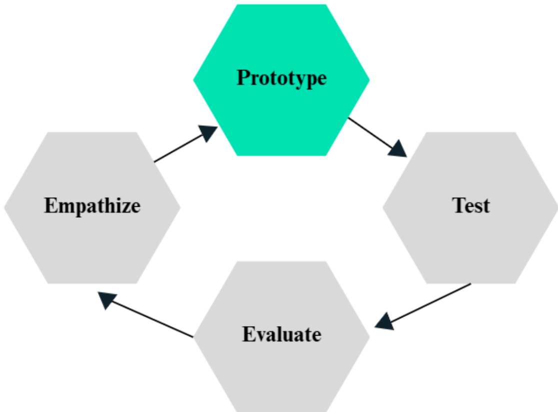


Fig. 14. Current stage of the doctoral process.

2.1 Instructional Design: What Is It and Why Is It Useful?

Instructional Design (ID) has emerged as a distinctive field at the intersection of education, psychology, and technology, devoted to the systematic planning of learning environments and experiences that foster effective and efficient acquisition of knowledge and skills. Its historical development can be traced to the early twentieth century, when the increasing use of audiovisual media in schools and training contexts, such as films, slides, and stereographs, gave rise to what was called the "visual instruction" and later the "audiovisual instruction" movement. These initiatives reflected an expanding awareness of the role of media in supporting education, culminating in large-scale applications during World War II, when audiovisual tools and training films were extensively deployed to rapidly and effectively prepare soldiers and workers (Reiser, 2001). The war experience demonstrated that systematic approaches to instruction could produce measurable outcomes in performance, thereby consolidating ID as a field grounded in both technological innovation and scientific inquiry.

Following these early applications, ID was increasingly shaped by the psychological theories of learning. Behaviorist principles, especially B.F. Skinner's programmed instruction, emphasized the decomposition of complex learning tasks into incremental steps, reinforced through feedback and repetition. Later, the cognitive revolution expanded the scope of ID by considering internal processes such as attention, memory, and problem solving, which informed more sophisticated instructional strategies. A seminal contribution was Robert Gagné's *Conditions of Learning* (1965/1985), which proposed that different types of learning outcomes (e.g., verbal information, intellectual skills, cognitive strategies, motor skills, and attitudes) require different instructional events. His model identified nine instructional events that correspond to internal cognitive processes, ranging from gaining attention to supporting retention and transfer, and remains a foundational reference for instructional designers.

From the 1970s onwards, the field consolidated its identity through systematic design models that sought to translate theoretical insights into replicable processes. Among the most influential frameworks is the ADDIE model (*see* also "Design-Based Research: the ADDIE Model" paragraph), which emerged from military and industrial training contexts. ADDIE represents a generic and iterative framework that emphasizes continuous evaluation and refinement, providing designers with a structured yet flexible process. Another widely recognized model is the Dick, Carey & Carey (1985), revised in subsequent editions), which adopts a systems perspective on instruction. It highlights the interdependence of components such as learning goals, instructional analysis, learner characteristics, performance objectives, assessment strategies, instructional materials, and formative evaluation. Unlike linear models, Dick, Carey & Carey (1985) emphasize feedback loops and adjustments, underscoring the iterative nature of instructional design.

At the same time, scholars have debated the epistemological and methodological foundations of ID. Merrill et al. (1996) argue that instructional design should be regarded as a technology grounded in instructional science, meaning that effective strategies must be empirically verified rather than determined by consensus or philosophical relativism. Instructional design, in this perspective, is analogous to engineering: just as aeronautical design must incorporate principles of aerodynamics, instructional design must integrate principles of learning discovered through scientific research. Conversely, Rowland (1993) highlights the creative and ill-structured nature of design, suggesting that instructional design shares characteristics with other design disciplines such as architecture or engineering. Rather than being purely rational and deterministic, the design of instruction involves intuition, iteration, and negotiation of constraints, resulting in solutions that are context-dependent and rarely reducible to a single optimal path.

Over time, the field has incorporated constructivist and socio-cultural perspectives, which challenge the assumption that learning is solely an individual and cognitive process. Constructivist-oriented models emphasize authentic tasks, learner agency, collaboration, and situated learning environments, underscoring the importance of meaning-making and knowledge construction. These approaches extend the scope of ID beyond the transmission of knowledge to the facilitation of experiences that enable learners to engage in exploration, problem-solving, and reflection.

In conclusion, instructional design can be understood as both science-based technology and creative design practice. Historically rooted in the use of media and systematic instructional strategies, the field has evolved to integrate diverse learning theories and design paradigms. The main models, ranging from Gagné's conditions of learning to ADDIE and the Dick, Carey & Carey (1985) model, provide structured processes that guide designers, while contemporary perspectives acknowledge the iterative, context-sensitive, and often uncertain nature of design. This dual orientation, towards scientific rigor and creative adaptability, constitutes the enduring strength of instructional design as a discipline central to education and training in diverse contexts. The application of instructional design frameworks in immersive learning environments extends the historical foundations of ID into contemporary contexts shaped by emerging technologies such as Virtual, Augmented, and Mixed Reality. While the origins of ID emphasized systematic planning and media integration (Reiser, 2001), and classical models such as Gagné's *Conditions of Learning*, ADDIE, and the Dick, Carey & Carey (1985) systems model provided structured processes for instructional development, recent empirical research shows that these frameworks are equally crucial in guiding the effective adoption of immersive technologies. In fact, explicit framework-guided implementations not only ensure systematic instructional development but also yield measurable improvements in learner engagement, accessibility, and cognitive performance.

For instance, studies employing Kolb's Experiential Learning Theory (1984) demonstrate how immersive environments can be designed to foster reflective observation and active experimentation, core processes of experiential learning. Kee, Zhang & King (2023) reported significant improvements in problem-solving, motivation, and practical skill development among design students using Augmented and Virtual Reality when activities were explicitly mapped to Kolb's learning cycle. Similarly, in healthcare education, the Morrison model has been shown to facilitate knowledge acquisition and skill development, as well as higher engagement levels, by structuring AR, VR, and MR interventions around task analysis, sequencing, and iterative evaluation (Asoodar et al., 2024). These findings suggest that immersive learning technologies reach their pedagogical potential only when anchored to systematic instructional design frameworks.

Beyond cognitive and skill-based outcomes, frameworks also enhance inclusivity and user experience. Poggianti et al. (2025) document how the Universal Design for Learning (UDL) framework, when applied to XR environments, increased accessibility by offering multiple means of representation, engagement, and expression. This approach is particularly relevant in higher education contexts seeking to accommodate diverse learner needs and reduce barriers to participation. Moreover, the ICAP framework (Interactive, Constructive, Active, Passive) has been employed to structure immersive learning interactions, demonstrating the importance of explicitly planning for levels of engagement to optimize cognitive load management (Conrad et al., 2024). Without such frameworks, studies frequently report inconsistency in outcomes, difficulties in aligning technology affordances with learning goals, and challenges in sustaining learner motivation (Won et al., 2022). Taken together, these results indicate that instructional design frameworks function as a critical bridge between the technological affordances of immersive environments and their pedagogical effectiveness. By providing structured guidance for curriculum integration, iterative refinement, and inclusivity, frameworks transform immersive technologies from novel tools into systematic and sustainable educational innovations. In this sense, the application of frameworks to XR, AR, and VR contexts represents a continuation of the ID tradition: as Merrill et al. (1996) argued, effective instructional strategies must be empirically validated and systematically implemented. Contemporary research on immersive learning confirms this principle, demonstrating that frameworks not only organize the design process but also enhance learning outcomes, engagement, accessibility, and overall user experience.

2.1.1 The Centrality of Experience in Immersive Learning

The notion of experience has increasingly emerged as a central construct in instructional design, positioning itself as the primary unit of analysis for both educational theory and practice. Traditional approaches often conceived instructional design in terms of discrete behavioral objectives or cognitive skills to be acquired. However, more recent perspectives argue that what is being designed is not simply a sequence of tasks or a repository of content, but rather a holistic *learning experience* (Parrish, Wilson, & Dunlap, 2011). Experience, in this sense, is not a static entity but a transactional construct: it involves the dynamic encounter between individuals and their world over time, integrating cognition, affect, agency, and identity. This conceptual shift places learners at the center of the design process, recognizing that powerful learning arises from contexts where intellectual, emotional, and social dimensions are deeply intertwined.

From an instructional design standpoint, framing learning as experience highlights the importance of attending simultaneously to multiple layers of human functioning. Parrish, Wilson, & Dunlap (2011) note that instructional design oriented to experiences must consider not only knowledge acquisition but also *aesthetic*, *affective*, and *identity-related* aspects of learning. Theories of aesthetic experience in education argue that meaningful learning events are those which resonate at a deeper level, engaging learners in ways that are memorable, transformative, and personally significant (Parrish, 2009; Wong, 2007). Instruction is thus envisioned as storytelling (Parrish, 2006), as the crafting of a narrative arc in which learners can situate themselves, experience emotional involvement, and emerge with new perspectives.

Contemporary research on digital and immersive learning has reinforced this orientation. Karthik et al. (2019), in their qualitative study of e-learning design strategies, identified six key themes, technical assistance, problem-based learning, aesthetics, gaming, storytelling, and social support, that directly contribute to the effectiveness of learning experiences. These findings confirm that learners' expectations are not confined to content delivery or technical performance but extend to the quality and meaningfulness of the experience as lived. Similarly, Anderson, Aylor, and Leonard (2008) argue that simulation should not be regarded as a technology per se, but rather as an educational strategy that amplifies real experiences through guided and planned experiences. In simulation-based learning, the sense of realism and suspension of disbelief, when coupled with structured reflection and feedback, enables learners to develop cognitive, technical, and behavioral skills in ways that transcend traditional instruction.

The centrality of experience in immersive learning can be further understood through perspectives that conceptualize education as a complex, contextual, and transformative process. Learning does not unfold through linear cause–effect mechanisms, but rather emerges from the dynamic interaction between individuals, environments, technologies, and organizational contexts, consistent with systems thinking and complexity theory (Ceruti, 2018). This aligns with contemporary work in educational systems that emphasizes contextual dependencies and emergent properties in learning (Davis & Sumara, 2006; Fenwick, Edwards & Sawchuk, 2015).

The centrality of experience is further elaborated in psychological and human–computer interaction research. Riva, Gaggioli, and colleagues have conceptualized immersive media as "experience technologies", capable of expanding the boundaries of perception, action, and self-awareness (Riva et al., 2016). In their review, they suggest that Virtual and Augmented Reality can foster *transformative experiences* by evoking a heightened sense of presence, embodiment, and emotional engagement, which in turn catalyze processes of reflection and change. This orientation resonates with the paradigm of Positive Technology (Gaggioli et al., 2019), which explicitly aims to design digital environments that promote well-being, motivation, and personal growth. Rather than focusing solely on risks or efficiency, Positive Technology emphasizes the intentional design of experiences that support flourishing at both the individual and social level.

The concept of *quality of experience* (QoE) has become a pivotal notion in this context. As Gaggioli, Bassi, and Delle Fave (2003) argue, the educational effectiveness of virtual environments depends less on technical sophistication than on the extent to which they create conditions for engagement, enjoyment, and meaning making. Similarly, research on optimal experience in Ambient Intelligence (Gaggioli, 2005; Riva, 2003) applies Csikszentmihalyi's theory of flow (1990) to demonstrate that interactive technologies can be designed to elicit deep involvement and intrinsic motivation, if challenge, skill, and feedback are well balanced. In this sense, immersive technologies are not valuable for their novelty alone but for their capacity to structure and sustain experiences that learners perceive as optimally challenging and rewarding.

An additional perspective comes from recent conceptual work on transformative experiences (TEs). Chirico et al. (2022) emphasize that transformative experiences are not limited to moments of sudden insight or dramatic change; they are complex phenomena that produce long-lasting consequences on beliefs, identity, and worldviews. The authors propose an integrated interdisciplinary framework, arguing that TEs can be deliberately fostered through conditions that support transcendence, reflection, and critical re-evaluation. For instructional design, this underscores the importance of designing for creating environments that do not simply transmit knowledge but have the potential to alter how learners perceive themselves and their place in the world.

Taking together these perspectives, they converge on a common principle: the value of instructional design and of immersive technologies lies not in the tools themselves, but in their ability to shape meaningful, multisensory, and multidimensional learning experiences. The MetaLab framework aligns with this trajectory by positioning experience, not technology, as the central unit of analysis. By doing so, it provides a systematic yet flexible structure for observing, designing, and evaluating educational interventions across the VR continuum, foregrounding the role of engagement, presence, and inclusivity.

Before detailing the structural components of the MetaLab model, it is important to clarify the theoretical foundations that inform its experiential orientation. The choice of this framework is grounded in the recognition that, to effectively integrate extended reality technologies into educational contexts, the unit of analysis should not be the technological device or platform itself, but rather the learning experience it enables (Laurillard, 2013; Mikropoulos & Natsis, 2011). Learning in XR is inherently multifaceted, engaging cognitive, emotional, embodied, and social dimensions simultaneously (Dede, 2009), and its pedagogical value lies less in the technical novelty of the tools than in their capacity to mediate, expand, and transform the ways in which students learn, interact, and construct meaning (Conrad, 2024). This perspective situates the MetaLab framework as a tool for observing, designing, and evaluating educational experiences across the VR continuum, emphasizing the quality and transformative potential of the learning process rather than the mere deployment of innovation (Milgram & Kishino, 1994).

Such a vision can be articulated along two complementary theoretical axes: first, the centrality of experience in learning, in continuity with Kolb's (1984) Experiential Learning Theory, which conceptualizes knowledge as a cyclical process of experience, reflection, conceptualization, and experimentation, and has been recently revised to highlight the dynamic, situated, and iterative nature of experiential cycles (Morris, 2020); and second, the transformative dimension of learning, in line with Mezirow's (1991) Transformative Learning Theory, which underscores the importance of critical reflection in reshaping frames of reference and perspectives of meaning. Taken together, these principles provide the conceptual grounding for situating the MetaLab model within the broader landscape of experiential and transformative education, orienting immersive educational design not toward technological experimentation per se, but toward the creation of environments that foster engagement, reflection, and transformation, thereby enhancing both the depth and the pedagogical impact of XR-based learning (Jarvis, 2012; Freitas & Neumann, 2009).

2.1.2 Experiential Learning Theory

Reflection on the importance of experience in learning took shape over the twentieth century, as several authors advanced theories and models that explicitly incorporated the concept of experience. The first is Kurt Lewin (1890–1947) who, through the theorization of action research and laboratory training, conceived learning as originating in here-and-now experience, followed by data collection and observation (Adelman, 1993; Kolb, 1984). Specifically, Lewin's experiential learning model (mirroring the method of action research) is structured as a cycle in which the starting point is concrete experience, followed by observation and reflection, then the formation of abstract concepts and generalizations, and finally the testing of the implications of the newly learned concepts in novel situations.

Subsequently, John Dewey, American philosopher and educational theorist, developed a theory which, despite only sporadic contact with Lewin (Colucci & Colombo, 2018), is closely aligned with his thinking: instrumentalism, which posits that experience is the foundation of human thought and action. From this perspective, the individual is not a passive observer of the surrounding world but an active agent interacting with it. Dewey is thus considered a proponent of educational activism, an approach that centers learning through action and direct experience. This current emphasizes the acquisition of practical competencies, in contrast to traditional approaches focused exclusively on knowledge transmission. Through this methodology, students can apply what they have learned and become protagonists of their own learning. The aim of educational activism is to create a motivating and engaging school environment that advances the principle of "learning by doing." In this way, it seeks to cultivate critical and autonomous thinking, providing learners with the competencies needed to face real-world challenges. Like Lewin, Dewey underscores the importance of concrete experience as the driving force of learning but adds that ideas provide direction to that impulse: his model places impulse as the starting point that activates observation, knowledge, and ultimately judgment, in an iterative dynamic culminating in the final purpose (Dewey, 1933; 1986; Kolb, 1984).

In the 1960s, part of the revival of experience-based learning was influenced by Swiss psychologist Jean Piaget (1952), whose work on the stages of cognitive development emphasized active learning and concrete experiences. In Piaget's theory (1952), experience is one of four interrelated factors shaping mental development. Among the stages of cognitive development, the earliest and most significant are the sensorimotor stage (0–2 years), the preoperational stage (2–6 years), and the concrete operational stage (6–12 years). Only with the final, formal operational stage does the adolescent become capable of fully abstract learning. In this sense, it is natural to think that human beings learn spontaneously first and foremost through experience. Accordingly, educators should foster experiential learning, in which students are actively engaged in meaningful situations relevant to their lives. This rests on the conviction that experiential learning helps students develop practical skills while also deepening their understanding of theoretical information (Kraft, 1990). Learning, as the learner develops, is a cycle of interaction between the individual and the environment, akin to Dewey's and Lewin's models. For Piaget, learning arises from a balanced tension between accommodation and assimilation: the accommodation of concepts or schemas to worldly experience, and the assimilation of events and experiences into existing concepts and schemas.

According to James Coleman (1977), a distinction exists between the assimilation process in traditional learning and experiential learning. In the traditional classroom, learning begins with the assimilation of information via symbolic means (e.g., lecture or textbook), proceeds to organizing information to grasp general principles, and culminates in applying the acquired knowledge in action. In practice, however, this model reveals notable shortcomings: as Brazilian philosopher Paulo Freire and other critics of contemporary education emphasize, modern schools rarely reach the final stage of action, stopping at the reflective stage of information assimilation (Freire, 1970; Kolb, 1984). In contrast, Coleman's experiential learning proceeds almost in reverse. Initially, there is no use of a symbolic medium to transmit information; rather, information is generated through the sequence of steps performed. Experiential learning thus consists in acting in a particular case and observing its effects. After grasping the effects and consequences of the action, the learner moves toward understanding the general principles involved and, finally, applies what has been learned through action in a new circumstance (Coleman, 1977).

It is based on these authors' work that David Kolb (1984) theorized his model of experiential learning. From Lewin, Kolb drew the centrality of action, considering that learning, change, and growth can be facilitated by an integrated approach linking theory and practice; from Dewey, he took the dialectic among elements and the circularity of the process; and Piaget's contribution confirmed for Kolb that, if the experiential learning process mirrors the child's development, starting from and returning to the concrete rather than relying solely on the abstract, then the model aligns with human nature and appears more suitable than the mere abstract assimilation of concepts.

Among existing models, Kolb's Experiential Learning Theory (ELT; 1984) is the most popular and influential (Seaman et al., 2017). In Kolb's theorization, the main characteristics of experiential learning are:

(i) learning should not be viewed as an outcome but as a process, since knowledge is not fixed and immutable, but is formed and re-formed through experience; consequently, (ii) learning is continuous and experience-based; (iii) learning entails resolving conflicts among different ways of relating to the world. To support this, Kolb (1984) revisits Lewin, Dewey, Piaget, and Freire, finding in their theories confirmation of dialectical tensions during learning, typically the learner's effort to bring concrete experience into contact with abstract conceptualization; and (iv) learning is a holistic process of adaptation to the world. By holistic, Kolb means that experiential learning is not merely an educational system but represents the way human beings adapt to their physical and social environment. The process therefore involves not only cognition and thought, but the whole organism (Kolb, 1984).

Building on these points, Kolb articulates a 4-phase model that synthesizes, from his perspective, the stages of learning through experience. This model, known as the Experiential Learning Cycle (ELC), a widely recognized as a foundational framework in the field of experiential education (De Girolamo, 2020). Kolb's model identifies four dialectically related modes of engaging with experience, each influencing and integrating with the others. The first two concern the perception of experience: (i) Concrete Experience (CE) and (ii) Abstract Conceptualization (AC); the latter two involve the transformation of experience: (iii) Reflective Observation (RO) and (iv) Active Experimentation (AE). Learning arises from the resolution of the creative tension among these four modes. Kolb (2014) presents this process as an idealized learning cycle in which the learner "touches all the bases," following a recursive path that is responsive to both the learning situation and the content being acquired (Fig. 15).

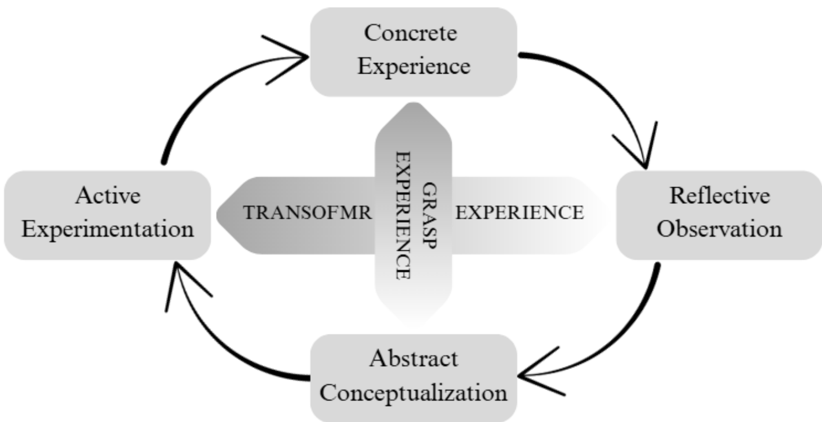


Fig. 15. Illustration of Kolb's experiential learning cycle, highlighting the recursive and dynamic process through which knowledge is created by transforming experience. Adapted from Kolb & Kolb (2009).

Concrete Experience emphasizes personal involvement in everyday situations and highlights the centrality of perception, sensation, and emotion in the learning process. These elements form the basis for Reflective Observation, where learning is grounded in listening, observing, and reflecting. Here, experience is analyzed and assessed objectively; attention is directed toward facts rather than emotions and meaning and connections are sought. These reflections are then assimilated into abstract concepts, marking the transition to the Abstract Conceptualization phase, where logic and conceptual reasoning are emphasized. Understanding a broader conceptual framework and acquiring theoretical models becomes crucial. In the Active Experimentation phase, learning occurs through direct engagement, and the learner actively attempts to influence the environment, introducing changes that can yield new insights for action. These implications can be tested and used to generate new experiences, which in turn loop back to the beginning of the cycle, as action is inherently inseparable from experience (Kolb, 2014).

Much of the research on learning styles has been conducted using the Kolb Learning Style Inventory (KLSI; Kolb, 2007), wherein a person's learning style is defined by their unique combination of preferences for the four learning modes (CE, RO, AC, AE). These preferences are shaped by genetic makeup, personal life experiences, and current environmental demands. Notably, ELT posits that learning style is not a fixed psychological trait but rather a dynamic state resulting from synergistic interactions between the individual and their environment. Subsequent clinical and empirical studies led to refinement of the original model, culminating in the KLSI 4.0, which proposes nine distinct learning styles (Kolb, 2007).

Kolb (2021) further posits that the combination of these four modes gives rise to four distinct learning styles: Diverging, Assimilating, Converging, and Accommodating. Individuals with a Diverging style emphasize observation and reflection on concrete experiences, often exhibiting imagination and emotional sensitivity. Assimilators, who favor Reflective Observation and Abstract Conceptualization, show a strong inclination toward theoretical disciplines and statistics; they gather data through observation, analyze it, and synthesize it into theoretical models. The Converging style, characterized by Abstract Conceptualization and Active Experimentation, is marked by a pragmatic approach to problem-solving, based on cost-benefit analysis and hypothetical-deductive reasoning. Finally, the Accommodating style privileges Concrete Experience and Active Experimentation, favoring action over words and intuition over analysis; such individuals tend to thrive in dynamic environments that require adaptability.

Beyond the classification of learning styles, Kolb and Kolb (2009) provide an essential *metacognitive* framing of the experiential learning process. They argue that learning is not merely the accumulation of experience but a recursive and self-aware process of meaning-making that engages learners in deliberate cycles of reflection, conceptualization, and experimentation. In contrast to conventional education models, what the authors term the "Performance Way", which prioritize speed, accuracy, and measurable outcomes, the "Learning Way" encourages openness to ambiguity, iterative dialogue, and the exploration of personal meaning.

Each phase of the Experiential Learning Cycle is thus associated with distinct metacognitive functions: RO entails emotional and cognitive monitoring; AC demands the articulation and organization of ideas; and AE requires intentional planning and behavioral self-regulation. Central to this process is the notion of *intentional learning*, a conscious, purposeful orientation toward growth, self-development, and the capacity to navigate complex, ill-defined problems. Through this lens, the learner becomes a "learning self", capable of adapting to change through ongoing cycles of inquiry and transformation. As a result, the educational environment must evolve beyond the delivery of content to cultivate metacognitive awareness, support reflective practice, and empower students to become active agents in shaping their own learning journeys.

2.1.3 Revisions and Extensions of the Experiential Learning Cycle Model

Kolb's work in the domain of experiential learning has laid a robust foundation for understanding how experiences are transformed into knowledge through the experiential learning cycle. Despite this, Kolb's ELT has faced conceptual and empirical critiques. Scholars have questioned whether the model describes sequential phases or static styles (Coffield et al., 2004), whether it adequately accounts for the role of social context (Jarvis, 2012), and whether the construct of "concrete experience" is sufficiently defined (Bergsteiner, Avery & Neumann, 2010). In response to these critiques, Morris (2020) conducted a systematic literature review and proposed a revised version of Kolb's learning cycle, aiming to clarify and enrich its pedagogical applicability. According to Morris, this revision was motivated primarily by the ambiguity surrounding the notion of "concrete experience." While Kolb conceptualizes learning as a holistic and transferable process applicable across domains, Morris argues that educators often interpret concrete experience as highly contextualized, practical, and situated in real-world environments. His revised model adds clarifying descriptors to each of Kolb's original stages, thus refining their instructional implications:

1. *Contextually Rich* Concrete Experience: this phase emphasizes the situated nature of learning. Students should engage in activities that are embedded in authentic, socially and culturally meaningful contexts, allowing them to recognize the deep connection between knowledge and its setting (Morris, 2020). This perspective aligns with Jarvis' (2012) critique of Kolb for insufficiently addressing the social dimensions of learning.
2. *Critical* Reflective Observation: Morris adds the adjective "critical" to underscore the importance of reflection as a mediating process for meaning making. Unlike Kolb, who does not emphasize criticality, Morris highlights the necessity for learners to interrogate assumptions and evaluate abstract concepts against real-world experiences (Barron et al., 2017).
3. *Contextual-Specific* Abstract Conceptualization: in this stage, learners are expected to develop generalizable insights while remaining attuned to the variability of contextual conditions. Morris (2020) stresses the importance of equipping learners with the ability to adapt theoretical frameworks to specific cultural, historical, and situational parameters.
4. *Pragmatic* Active Experimentation: the final phase involves real-world application marked by uncertainty and risk. Drawing on Roberts (2018), who links the etymology of *experience* to the Latin *expereri* (i.e., to test or take a risk), Morris redefines this phase as a pragmatic endeavor requiring learners to actively adapt and respond to dynamic, ill-defined problems.

However, Morris' revision leaves open certain theoretical questions. For instance, Jarvis (2012) advocates for bidirectional arrows between phases to accommodate non-linear learning trajectories, such as instances in which abstract conceptualization precedes concrete experience or when reflection occurs simultaneously with action (*reflection-in-action*). These refinements suggest that the experiential learning cycle should not be regarded as a rigid sequence but a flexible, recursive process that varies according to task, learner, and context. Numerous empirical studies support the positive impact of Kolb's ELT and its learning cycle on academic performance across various disciplines in higher education. Learning style preferences, as conceptualized within the ELT framework, have been shown to vary significantly across academic domains and are closely linked to student achievement. Jones, Reichard & Mokhtari (2003), for instance, found that students' learning styles differed according to their field of study and GPA scores, suggesting that instructional design aligned with Kolb's model may benefit from discipline-specific customization. Healey and Jenkins (2000) demonstrated that the application of ELT in university-level geography education not only provides an effective structure for course development but also enhances awareness of diverse learning approaches among students.

These findings are further corroborated by evidence from cognitive psychology. Richmond et al. (2024) investigated the "testing effect" across multiple academic disciplines and found that test-enhanced learning, functionally aligned with Kolb's Active Experimentation phase, significantly improves both lower- and higher-order cognitive skills, thus reinforcing the value of active engagement strategies in experiential pedagogy. Complementary evidence from institutional reviews highlights that ELT has been successfully adopted to design learning environments that foster metacognitive development and support both faculty and student growth across diverse academic fields (Kolb & Kolb 2006).

Taken together, this body of evidence suggests that Kolb's experiential learning cycle holds substantial potential to enhance academic performance, especially when its principles are thoughtfully adapted to disciplinary contexts, instructional strategies, and student-teacher alignment. Both Kolb's ELT and its subsequent revisions have significantly shaped educational practices by illuminating how experiences can be structured to foster reliable and transformative learning.

2.1.4 Transformative Learning Theory

Transformative Learning (TL) was first articulated by Jack Mezirow (1991) as a theory that explains how adults revise the very structures through which they make meaning of experience. At its core, Mezirow describes transformation as a deep, structural change in a person's "meaning perspective" that alters how events, relationships and the self are interpreted. This idea draws on earlier theoretical currents, Kuhn's notion of paradigm shifts, Freire's conscientization and Habermas's emphasis on communicative rationality (Kuhn, 1997; Freire, 1970; Habermas, 1985), and was initially derived from Mezirow's empirical work with women returning to education in the 1970s (Kitchenham, 2008).

Mezirow's framework (1991) contains several interlocking constructs that account for how perspective transformation occurs (Kitchenham, 2008; Illeris, 2004).

- *Meaning schemes and meaning perspectives*: meaning schemes are clusters of specific beliefs, feelings and judgments that guide interpretation; meaning perspectives are broader structures (epistemic, sociolinguistic and psychological) that organize sets of meaning schemes. Transformation can therefore involve changes at the level of individual schemes or a more comprehensive reorganization of a whole perspective.

- *The disorienting dilemma and the phase model*: transformation is often initiated by a disorienting dilemma, an anomaly or crisis that cannot be assimilated into existing meaning schemes, followed by a recursive sequence of reflection, discourse, exploration of new roles, trial, and reintegration. Mezirow originally described a ten-phase sequence (later revised and expanded), which remains a widely used heuristic for analyzing transformative processes.
- *Critical reflection and communicative discourse*: two mechanisms are central to genuine transformation: (i) critical self-reflection on the assumptions that underlie one's meaning schemes (including content, process and premise reflection); and (ii) dialogic validation through rational discourse, where learners test alternative interpretations in conditions ideally free from coercion. Mezirow situates these mechanisms within a normative commitment to reasoned argument as a route to justified perspective change.
- *Learning types and the role of emotion and social contex*t: subsequent theorists have expanded and problematized Mezirow's initial, largely cognitive account. Illeris (2004) proposes that learning always unfolds across three interrelated dimensions: (i) cognitive, (ii) emotional, and (iii) social, and that transformative learning is the most comprehensive type of learning, involving simultaneous restructuring across those dimensions. Illeris's framework (2004) insists that to explain full personality or life-world transformations we must account explicitly for affect, motivation and socio-communicative processes, not only cognitive reframing. In practice, this means transformations are often embodied, relational and socially situated as well as intellectual.

Transformative learning theory has been subject to sustained critique and refinement. Key criticisms include: an overemphasis on rationality and cognition at the expense of affective, somatic and spiritual ways of knowing; insufficient attention to power, culture and social structures that constrain discourse; and questions about whether Mezirow's phase model is universally applicable across cultures and contexts. Mezirow and subsequent scholars have responded by clarifying distinctions (e.g., point of view vs. habit of mind), elaborating the role of emotions in the process, and by incorporating social and dialogic dimensions more explicitly. Empirical and practice-oriented scholarship has therefore both validated central Mezirowian constructs and pushed for a more pluralistic, context-sensitive understanding of transformation.

Applied work (Christie et al., 2015) shows how TL can be deliberately supported in adult and higher education. Practical strategies include designing carefully staged "dilemmas" (e.g., values surveys, role-plays, cross-cultural immersion), structuring guided critical reflection tasks, and creating low-coercion spaces for sustained dialogue and peer challenge. Case studies combining action research and TL (for example, workshops and values exercises employed with returning students, PhD cohorts and in in-service teacher programs) demonstrate measurable shifts in learners' epistemic orientations, classroom practices and sense of agency, especially when interventions attend both to reflective cognition and to the emotional/social conditions that enable safe exploration of alternative perspectives.

Quantitative findings, though limited in number, are especially informative about the effectiveness of TL in education. Bullen and Roberts (2019), analyzing a large cohort of first-year health-science undergraduates (N = 336), found that measures of critical reflection were the *strongest predictor* of transformative outcomes and mediated the relationship between deep learning approaches and transformation. Walters et al. (2017), in short-term study-abroad samples, reported that participation in reflective journaling combined with service-learning activities produced significantly higher critical reflection scores, an effect that was interpreted as the proximal route to gains in critical thinking and global civic sensibilities. These quantitative signals are complemented by convergent qualitative evidence: Pfeiffer et al. (2022), Fetherston and Kelly (2007) and Zanchetta et al. (2017) consistently described that program features which provided structured opportunities for reflection and dialogic exchange were associated with observable cognitive reorientation, changes in meaning schemes and, in some cases, behavioral experimentation consistent with perspective transformation.

Beyond critical reflection, the studies identify *supportive relational and environmental facilitators* that enable reflection to produce deeper cognitive change. Bullen and Roberts (2019) emphasized student–teacher rapport and a cohesive classroom community as predictors of learners' readiness to engage in honest, sustained reflection. Collins et al. (2022), studying a five-week virtual exchange, found that openness and relatedness in mediated environments increased students' willingness to question assumptions, indicating that technological contexts can foster transformative processes when they cultivate psychological safety and cross-cultural connectedness. Pfeiffer et al. (2022) and Fetherston and Kelly (2007) further highlight that experiential or skills-based components (e.g., role-play, service tasks, conflict-resolution simulations) disrupt routine epistemic habits and stimulate empathetic engagement, outcomes that qualitative accounts linked to both critical thinking gains and affective shifts.

The included studies also demonstrate the *interconnected* nature of mechanisms: combinations such as (i) critical reflection + classroom rapport, (ii) self-reflection + skills training, (iii) experiential learning + critical dialogue, and (iv) reflective journaling + service learning were reported more effective than isolated techniques. For example, programs that paired reflective prompts with mentor-facilitated discussion or with real-world practice tended to report not only higher reflection scores but also evidence of movement across learning levels (i.e., cognitive → emotional → behavioral). This pattern suggests that reflection functions as the cognitive engine of transformation, while relational, experiential and contextual elements act as catalysts that amplify reflection's effect.

However, important caveats limit generalizability. Methodological heterogeneity (qualitative vs quantitative designs), small sample sizes in several studies (e.g., Pfeiffer et al., N = 48; Walters et al., N = 20) and incomplete demographic reporting for many samples reduce the strength of causal claims. Only two studies reported quantitative effect metrics, constraining any meta-analytic synthesis of effect magnitudes. Reliance on self-report instruments and reflective artefacts also introduces likely measurement and social-desirability biases. Finally, the corpus shows a generally positive reporting bias: null or adverse outcomes were not described, signaling the need for preregistered, controlled trials and more rigorous longitudinal follow-ups.

Implications for practice flow directly from these results. To foster undergraduate critical thinking via TL principles, instructional designs should (i) embed structured, scaffolded reflection (journals, guided prompts, critical self-assessment) as a central element; (ii) combine reflection with experiential activities (service learning, simulations, fieldwork) that produce disorienting but supported dilemmas; (iii) cultivate classroom climates and teacher–student relationships that enable open, low-coercion dialogue; and (iv) attend explicitly to affective and relational dimensions, particularly in virtual or cross-cultural settings, to increase learners' openness to revise assumptions.

While Mezirow's framework highlights the cognitive mechanisms of perspective transformation, adult education research underscores that transformation is also embedded in social, cultural, and organizational contexts (Brookfield, 2005; Taylor & Snyder, 2012). For instance, Roberto Tramma discusses learning as transformation within contemporary social complexities (Tramma, 2019), whereas Paolo Orefice and Paolo Federighi frame it as lifelong, situated and context-dependent, arising from interactions among personal goals, institutional norms, and professional practices (Pollo, 2004; Federighi, 2018). These contributions extend transformative learning beyond individual cognition to include relational and contextual factors, offering a richer interpretation of how immersive environments can foster change in higher education. They are particularly relevant in XR contexts, where engagement, gamification and social dynamics intersect (Sailer & Homner, 2020).

These empirical examples illustrate how Mezirow's ideas can be operationalized while also responding to calls to incorporate affective, cultural and power-sensitive elements. TL remains a generative framework for understanding deep changes in adult meaning-making. Its continued development has moved it from a primarily cognitive model toward a more integrative, multidimensional conception that recognizes emotionality, embodiment and sociocultural context as integral to transformation. For researchers and educators, the pragmatic lesson is twofold: (i) design interventions that systematically elicit critical reflection and discursive testing of assumptions; and (ii) embed those activities in learning ecologies that explicitly address emotion, identity and social structure so that perspective change is both meaningful and sustainable.

2.2 A New Instructional Design Framework: The MetaLab Model

As summarized in Tab. 7, the MetaLab model originates from the integration of established theoretical perspectives on experiential and transformative learning with the empirical evidence gathered during the initial *Empathize* phase of the doctoral project. Its principles do not derive exclusively from general theories of learning but are the result of a process that combined theoretical frameworks with the concrete perceptions and needs expressed by students and faculty members involved in the workshops and the study (*see* Chapter 1).

Tab. 7. Mapping of Empathize Phase Insights (Faculty and Students) to the MetaLab Instructional Design Principles.

Empathize Phase Insights	Stakeholder Group	Corresponding Principle	Explanation of Alignment
Faculty and students rapidly adapted to XR technologies, showing curiosity and openness during onboarding despite limited prior experience.	Faculty & Students	*Learner-centric design*	Emphasized the importance of intuitive, user-centered onboarding and the design of accessible learning experiences tailored to users' prior knowledge and expectations.
Facilitators were essential in scaffolding learning and overcoming discomfort among novice users.	Faculty	*Continuous feedback integration*	Highlighted the need for ongoing facilitation, user support, and iterative refinement — core mechanisms of the MetaLab's feedback-driven design cycle.
XR environments elicited curiosity, surprise, and wonder, fostering deep engagement and inquiry.	Faculty & Students	*Epistemic emotions*	Empirical evidence supported designing XR scenarios that intentionally evoke epistemic emotions to enhance motivation, understanding, and retention.
Immersive activities promoted creative collaboration, peer assistance, and shared meaning-making.	Faculty	*Collaborative learning*	Validated the model's focus on fostering group flow and co-construction of knowledge through immersive and social learning dynamics.
Faculty reported strong emotional engagement and reflective thinking during immersive experiences.	Faculty	*Transformative experience*	Confirmed XR's potential to promote perspective transformation and deep learning through experiential and reflective engagement.
XR enabled the simulation of complex and interactive real-world scenarios, enhancing conceptual understanding.	Faculty	*Immersive learning*	Reinforced the centrality of using XR to create authentic, experiential contexts that go beyond classroom constraints.
Faculty appreciated XR's ability to turn abstract concepts into concrete, experiential representations.	Faculty	*Storytelling*	Supported integrating narrative and visual metaphors to make learning more meaningful and memorable.
XR facilitated remote participation and cross-location collaboration.	Faculty	*Adaptability and accessibility*	Provided the rationale for multi-access, inclusive design strategies enabling participation regardless of spatial or physical constraints.
Participants expressed concerns about device ergonomics, usability, and accessibility.	Faculty	*Technology-agnostic & Adaptability and accessibility*	Informed the model's emphasis on designing for comfort, equity, and pedagogical purpose rather than technological novelty.
Faculty highlighted the scarcity of XR-ready, discipline-specific content and the need for curriculum integration.	Faculty	*Problem & project-based learning*	Inspired the integration of authentic, domain-specific XR projects aligned with curricular objectives and co-designed with educators.
Faculty expressed the importance of institutional support and iterative experimentation.	Faculty	*Continuous feedback integration*	Reinforced the inclusion of participatory co-design cycles and continuous evaluation in the MetaLab framework.
Students' expectations before using IVR (performance and effort expectancy) did not predict confirmation.	Students	*Learner-centric design*	Highlighted the importance of grounding design decisions in actual experiences and needs rather than assumed expectations.

Empathize Phase Insights	**Stakeholder Group**	**Corresponding Principle**	**Explanation of Alignment**
Confirmation (alignment between experience and expectations) strongly predicted perceived usefulness, satisfaction, and self-efficacy.	Students	*Transformative experience & Epistemic emotions*	Demonstrated that experiential congruence drives positive emotional and cognitive outcomes, key to transformative and epistemic learning processes.
Perceived usefulness, satisfaction, and self-efficacy significantly predicted continuance intention.	Students	*Immersive learning & Continuous feedback integration*	Indicated that sustained engagement depends on designing immersive activities that are both meaningful and manageable, encouraging long-term adoption.
The experiential alignment between expectations and actual use emerged as critical to sustained engagement.	Students	*Learner-centric design & Transformative experience*	Showed that designing XR experiences that meet learners' expectations fosters motivation, satisfaction, and personal growth.
Students developed confidence (self-efficacy) through repeated interaction with IVR tools.	Students	*Adaptability and accessibility*	Informed the principle of scaffolding confidence and digital fluency through gradual, inclusive exposure and supportive design.

Indeed, the analysis of these data highlighted three themes that became central to the model: (i) transformation, (ii) emotional engagement, and (iii) creative collaboration. Faculty members pointed to the capacity of immersive environments to stimulate critical reflection and emotions, consistent with the assumptions of transformative learning theory (Mezirow, 1991). Students, by contrast, stressed the affective intensity of XR experiences, reporting emotions such as curiosity, wonder, and occasionally frustration, in line with research on epistemic emotions as drivers of inquiry and deeper processing (Pekrun, 2006; D'Mello et al., 2014). Both groups also identified the potential of immersive contexts to foster collaboration, peer support, and shared meaning-making, echoing the emphasis on collaborative creativity found in the educational literature (Sawyer, 2017).

Through the convergence of these empirical findings with theoretical frameworks, the MetaLab model was defined around three design principles:

- *Facilitating Epistemic and Personal Transformation.* Drawing on the theoretical framework proposed by Paul (2014), MetaLabs are designed to elicit experiences that are both epistemically and personally transformative. Experience is considered *epistemically transformative* when it provides access to novel forms of knowledge or understanding that were previously inaccessible or unimaginable, for instance, encountering a new perceptual phenomenon or a radically different cultural perspective. *Personally transformative* experiences, on the other hand, are those that deeply affect an individual's preferences, identity, or core values, such as becoming a parent or undergoing a profound moral shift. Within MetaLabs, immersive virtual environments are intentionally crafted to enable both types of transformation by immersing learners in emotionally charged, novel contexts that challenge their assumptions and invite critical self-reflection. VR has been shown to be particularly effective in facilitating transformative experiences due to its capacity to evoke a strong sense of *presence* and to foster intense emotional and cognitive engagement (Gaggioli, 2016; Riva et al., 2016). By placing users in embodied simulations of unfamiliar or value-laden scenarios, VR amplifies the salience of experience and catalyzes processes of meaning-making and identity negotiation. These affordances are central to the MetaLab design, which aims to not only expand participants' knowledge base but also to stimulate deeper shifts in their self-concept and worldview.

- *Fostering Emotional Engagement Through Epistemic Emotions***.** Another cornerstone of the MetaLab approach is the deliberate cultivation of *epistemic emotions*, a class of emotions intimately linked to processes of knowledge acquisition and cognitive exploration. Emotions such as curiosity, surprise, wonder, and awe have been shown to play a central role in motivating learning, enhancing attention, promoting critical inquiry, and supporting memory consolidation (Muis, Chevrier & Singh, 2018; Vogl et al., 2019, 2020). These emotions not only foster intrinsic motivation but also serve as cognitive catalysts, encouraging learners to interrogate their preconceptions and engage in deeper information processing, often triggered by moments of surprise, confusion, or intellectual conflict. MetaLabs leverage the immersive affordances of XR to evoke such epistemic emotions through open-ended challenges, narrative-driven scenarios, and sensory-rich environments. For example, prior studies have demonstrated that VR experiences designed to simulate vast or awe-inspiring landscapes can reliably elicit the emotion of *awe*, a complex emotion that expands perception, promotes prosocial behavior, and facilitates epistemic openness (Chirico et al., 2017, 2018). By strategically embedding such affective triggers within learning activities, MetaLabs aim to activate the emotional dimension of learning and thus deepen the learner's engagement and long-term retention.
- *Encouraging Creative Collaboration and Group Flow***.** In addition to individual transformation and emotional immersion, MetaLabs are designed to foster *creative collaboration* by enabling the emergence of *group flow*, a shared state of optimal experience where collective engagement, creativity, and coordination are maximized. Building upon Csikszentmihalyi & Csikzentmihalyi (1990) foundational theory of flow, the concept of *Networked Flow* (Gaggioli et al., 2012, 2020) extends the experience to collaborative settings, describing conditions under which group members synchronize their actions, goals, and cognitive efforts to achieve collective efficacy. Key to enabling Networked Flow is the cultivation of *we-intentionality*, the shared intentional stance that arises from mutual trust, co-regulation, and a strong sense of *social presence* (i.e., the perception of being together in a shared space, even if virtual). MetaLabs actively support this dynamic by providing tools for co-creation, synchronous interaction, and continuous feedback. Collaborative tasks are designed to balance challenges and skill at the group level, maintaining the conditions necessary for flow without inducing cognitive overload.

To reinforce the creative process, MetaLabs incorporate virtual environments that function as collaborative studios or "maker spaces," allowing learners to co-construct artifacts such as visual narratives, simulations, or multimedia prototypes. The tangible expression of group creativity is not only central to consolidating learning but also to enhancing collective identity and recognition.

In summary, the three design principles of the MetaLab model are intended to synergize immersive technologies with advanced pedagogical strategies to promote deep learning, transformative growth, and collaborative creativity. By integrating these elements within a metacognitively rich XR environment, MetaLabs can offer a powerful paradigm for learning. The core characteristics of the MetaLab instructional design model are summarized in Tab. 8, and serve as guiding elements in the planning, facilitation, and evaluation of MetaLab learning experiences.

Tab. 8. Key Characteristics of the MetaLab Instructional Design Model

Instructional design principle	Description
Learner-centric design	Focuses on the needs, expectations, and experiences of students and teachers, placing them at the center of the learning experience design process.
Immersive learning	Utilizes XR technologies to create highly immersive and interactive learning environments that transcend traditional classroom boundaries.
Technology-agnostic	While leveraging XR technologies, the model emphasizes the learning experience over the technology itself, ensuring pedagogical goals drive technology use.
Transformative experience	Incorporates principles from transformative learning theory and experiential learning theory to support deep learning and reflection. Aims at providing both Transformative experiences epistemically and personally transformative learning experiences, leveraging XR to facilitate profound changes in understanding, perspectives, and self-conception.
Epistemic emotions	Designs learning scenarios that evoke epistemic emotions (e.g., curiosity, surprise, awe) to enhance engagement, understanding, and retention.
Storytelling	Utilizes storytelling and emotional engagement strategies to make learning experiences more relatable and memorable.
Collaborative learning	Encourages creative collaboration among students, utilizing XR to support group flow and shared experiences in virtual environments.

Adaptability and accessibility	Ensuring learning experiences are adaptable to different technological access levels and inclusive of di verse learner needs.
Continuous feedback integration	Emphasizes the importance of iterative design and user feedback to refine and improve learning experiences continuously.
Problem & project-based learning	Integrates innovative teaching strategies, such as PBL and PjBL, to blend theoretical knowledge with practical application.

Following the definition of its theoretical and empirical foundations, the MetaLab model now progresses toward the prototyping phase, which focuses on the creation of the immersive laboratories themselves. This stage marks the transition from abstract design principles to the practical implementation of structured environments where the model can be operationalized and evaluated. To enable this process, two core components of the framework are introduced in the next sections: the role of the *Immersive Learning Designer*, a professional profile responsible for aligning pedagogical objectives with technological affordances, and the co-design process with university faculty, through which the MetaLabs were collaboratively defined. Together, these components provide the methodological foundation for translating the MetaLab model into applied immersive learning experiences.

2.3 From MetaLab Model to Co-Design: Bridging Theory and Practice

To fully understand the role of co-design within the MetaLab project, it is essential to situate this phase as a methodological bridge between the user research made in the *Empathize* phase described in Chapter 1 and the activities that will be presented in the next paragraph. The needs, expectations, and constraints identified through the initial inquiry with students and faculty members did not merely constitute background information; rather, they directly informed the priorities and directions of the co-design process. For example, the request for more inclusive and flexible learning formats, as well as the recognition of time and technological constraints within the academic setting, guided the identification of design requirements and oriented the subsequent prototyping activities.

In this sense, the co-design workshops and the study made with university students were not conceived as an isolated procedural step, but as the operational translation of the theoretical underpinnings discussed in the Methodological approach used in the present doctoral work (*see* Introduction).

As previously presented, the approach used in this doctoral work was grounded in the principles of *Design-Based Research* (Brown, 1992; Collins, 1992; Anderson & Shattuck, 2012), which emphasizes the iterative cycles of design, implementation, and reflection in authentic educational contexts, and in *Design Thinking* traditions (Gagné, 1985; Reigeluth, 1999), which highlight the systematic planning of learning experiences.

These frameworks were not applied in canonical forms but were adapted to the specificities of the higher education context, where flexibility, interdisciplinarity, and experiential quality were prioritized over rigidly standardized procedures. In this way, the co-design process became both a methodological and a pedagogical device: it enabled the collaborative generation of viable design solutions while simultaneously embodying a participatory and learner-centered vision of educational innovation.

The involvement of faculty members as co-designers played a pivotal role in the *Prototyping* phase. Their contribution was not limited to providing feedback on pre-structured proposals; rather, they actively participated in generating, refining, and selecting ideas that were subsequently translated into concrete immersive learning classes, the MetaLabs. This participatory stance ensured that the emerging designs were aligned with both disciplinary expertise and pedagogical priorities, increasing their relevance and feasibility within the institutional context. By valorizing the agency of faculty, the co-design process also fostered a sense of ownership and responsibility, which proved crucial for the subsequent phases of adoption and evaluation. Finally, the prototypes developed collaboratively were systematically integrated into the instructional design framework, serving as the basis for the empirical protocol that would test the effectiveness, inclusivity, and experiential quality of the MetaLab interventions. This continuity underscores the integrative logic of the project: user research informed co-design, co-design produced prototypes, and prototypes grounded the evaluation process.

In the next subsections, these aspects will be examined in greater detail: Section 2.3.1 will outline the MetaLab Co-Design Process, Section 2.3.2 will describe the MetaLab Design Workflow with Faculty Members, and Section 2.3.3 will introduce the role of the Immersive Learning Designer (ILeaD) within the project.

2.3.1 The Immersive Learning Designer (ILeaD)

The user research conducted during the *Empathize* phase highlighted not only the pedagogical opportunities of immersive learning but also a series of challenges faced by faculty members in integrating XR technologies into their teaching. While instructors expressed curiosity and interest in experimenting with immersive environments, they also reported difficulties related to technical complexity, limited confidence in using unfamiliar tools, and uncertainty about how to align XR activities with specific learning goals. These findings echoed barriers widely discussed in the literature, such as lack of adequate training, insufficient institutional support, and the perception of technology as an additional burden rather than a pedagogical resource (Abrahams, 2010; Beggs, 2000; Porter & Graham, 2016; Mirriahi et al., 2012).

To address these challenges, the project formalized the role of the Immersive Learning Designer (ILeaD) (Fig. 16), a professional profile conceived as a bridge between pedagogy, technology, and psychology. The creation of this role responded directly to the need for dedicated support identified during the initial inquiry, ensuring that faculty members could rely on an expert able to translate educational goals into immersive learning scenarios while simultaneously providing guidance and training throughout the design and implementation process. The ILeaD's responsibilities included not only selecting and adapting XR platforms to pedagogical objectives but also facilitating collaboration during co-design workshops, anticipating accessibility needs, and ensuring that immersive experiences were inclusive, engaging, and educationally effective.

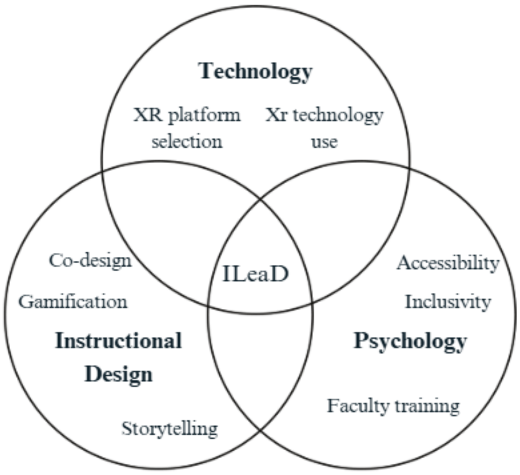


Fig. 16. Illustration of the Immersive Learning Designer as a bridge between instructional design, technology, and psychology, highlighting core responsibilities such as co-design, XR platform selection, inclusivity, faculty training, and gamification.

In this sense, the ILeaD emerged as a cornerstone of the MetaLab workflow, enabling faculty members to overcome both technical and psychological barriers and fostering a more confident and creative integration of XR into higher education. This role became particularly significant during the co-design phase, where the presence of the ILeaD ensured that workshops with instructors were not limited to idea generation but evolved into structured and feasible instructional designs.

At its core, the primary responsibility of the Immersive Learning Designer (ILeaD) is to design immersive learning environments that are coherently aligned with pedagogical objectives. This reflects a key principle in instructional design: technologies are not neutral tools but must be deliberately shaped to support intended learning outcomes (Laurillard, 2013; Gagné, 1985). The role involves the identification or development of virtual spaces, simulations, and interactive scenarios that enable students to engage with learning materials in innovative and meaningful ways. From a constructivist perspective, effective immersive learning experiences must allow learners to actively construct knowledge through authentic tasks and situated contexts (Jonassen & Rohrer-Murphy, 1999; Herrington, Reeves & Oliver, 2010). The ILeaD collaborates closely with faculty members to translate instructional goals into immersive activities, ensuring that XR integration enhances, rather than complicates, the teaching–learning process. This aligns with the framework of Technological Pedagogical Content Knowledge (TPACK; Mishra & Koehler, 2006), which emphasizes the necessity of harmonizing technological affordances with pedagogical strategies and disciplinary content.

Beyond technical expertise, the ILeaD is expected to possess a comprehensive understanding of pedagogical principles as well as psychology and learning theories. This interdisciplinary expertise reflects the consensus that effective immersive learning requires attention not only to usability and technical robustness but also to cognitive and affective dimensions of the learner experience. For example, theories of experiential learning (Kolb, 1984; Morris, 2020) and transformative learning (Mezirow, 1991) highlight the importance of experience, reflection, and perspective transformation in educational processes. Similarly, cognitive load theory (Sweller, 1994) suggests that immersive environments must be carefully designed to balance mental demand, ensuring that the novelty and sensory richness of XR do not overwhelm learners' processing capacity. In this sense, the ILeaD's role in anticipating accessibility and inclusivity issues echoes universal design for learning (UDL) principles (Meyer, Rose, & Gordon, 2014), which advocate flexible, equitable, and adaptable learning experiences.

Another central dimension of the ILeaD's work lies in providing continuous support and training for faculty. Literature on technology adoption in higher education consistently identifies lack of training and institutional support as major barriers (Beggs, 2000; Porter & Graham, 2016; Mirriahi et al., 2012). Faculty often approach immersive technologies with enthusiasm but also with uncertainty, limited confidence, and anxiety about disrupting established teaching routines (Abrahams, 2010). Professional development and scaffolding, as offered by the ILeaD, are therefore essential to reduce resistance and to foster both digital self-efficacy and pedagogical innovation (Ertmer & Ottenbreit-Leftwich, 2010).

In addition, the ILeaD's expertise in gamification and interactive design represents a critical asset for enhancing engagement. Research on gamification in education demonstrates that game elements such as challenge, feedback, and narrative can foster motivation and sustained participation (Deterding et al., 2011; Hamari et al., 2014). Similarly, the use of interactive storytelling and narrative-based immersive scenarios has been shown to promote emotional engagement and deeper comprehension by situating learning within meaningful contexts (Gee, 2003; Ryan, 2015). In XR-based pedagogy, the integration of game mechanics and interactive narratives aligns with experiential and constructivist paradigms, allowing students to become active participants rather than passive recipients of information (Dede, 2009; Mikropoulos & Natsis, 2011).

By aligning instructional goals with XR affordances, grounding design in learning theories (constructivism, experiential learning, transformative learning), ensuring accessibility and inclusion, supporting faculty adoption (technology adoption frameworks), and leveraging gamification to sustain motivation, the ILeaD enables immersive technologies to function not as an external burden but as a meaningful and transformative educational resource.

2.3.2 The Metalab Design Workflow with Faculty Members

The co-design phase of the MetaLab project was initiated by re-engaging faculty members who participated in the exploratory workshops conducted during the first stage of the research. These instructors were invited via a follow-up email to join the second phase, which focused explicitly on the collaborative design of MetaLab learning experiences. This continuity was crucial for ensuring that the design process was not developed in isolation, but rather directly built upon the needs, constraints, and pedagogical interests that had emerged in the initial user research.

The design of MetaLab learning experiences follows a structured yet adaptive workflow that blends participatory design, user-centered research, and the strategic integration of XR technologies. Rooted in the principles of transformative learning and co-construction, this workflow is articulated through three co-design meetings with university faculty members. Each meeting serves a specific function within the design process: the first focuses on exploring pedagogical needs and expectations, the second on translating these insights into concrete design choices and XR scenarios, and the third on refining the proposed solutions to ensure alignment with both learning objectives and technological feasibility. By involving faculty at multiple stages, the workflow ensures that the resulting immersive experiences are pedagogically meaningful, technologically viable, and contextually relevant. As illustrated on Fig. 17, the MetaLab design process is articulated into three main meetings (see Chapter 4 for a detailed description of the MetaLab toolkit supporting this process).

1. Meeting 1- *Profiling*: focuses on the identification of learning goals, and the contextual analysis of learner needs. At this stage, the emphasis is placed on defining the key knowledge areas, skills, and competences to be developed, while also examining learner characteristics such as prior experience with XR, digital literacy, and disciplinary background. The outcome of this first meeting is the establishment of a shared pedagogical foundation that will guide subsequent design choices.
2. Meeting 2 – *Consolidation*: is dedicated to the co-design of the learning experience through a series of structured workshops with university faculty. Unlike the first meeting, which is primarily analytical, this stage is creative and collaborative: faculty members, supported by the ILeaD and technical experts, engage in design thinking activities to explore pedagogical opportunities, articulate constraints, and make collective decisions about instructional strategies and XR applications. Within this meeting, the selection of the XR platform and the development of tailored content take place, ensuring that pedagogical intentions are effectively translated into technological solutions. Examples of outputs include narrative-driven simulations, scenario-based exercises, and virtual field explorations adapted to the disciplinary context.
3. Meeting 3 – *Refinement*: shifts the focus from design to implementation and refinement. Here, a prototype of the MetaLab experience is developed and tested through formative evaluation. Professors, and, when feasible, students, are invited to interact with the prototype and provide structured feedback on usability, accessibility, and learning effectiveness. This feedback is systematically analyzed and used to refine the design, ensuring that the final experience aligns with pedagogical goals and user expectations. In this way, meeting 3 operationalizes the principles of design-based research by embedding evaluation and iterative redesign within the prototyping process.

Fig. 17. The MetaLab Design Workflow articulated in three meetings (i.e., Profiling, Consolidation, Refinement). AI-generated images created with ChatGPT [OpenAI, GPT-5, 2025 version].

By following this workflow and actively involving the university faculty who took part in the experiential workshops, a total of sixteen MetaLabs were developed and then implemented in real university courses; these will be presented in detail in Chapter 3. To provide a concrete example of the MetaLab instructional design workflow, a description of a MetaLab titled "*Virtual Tour of Milan's Chinatown*", inscribed in the university course "Geography with Laboratory," led by Professor M. is now detailed.

1. Meeting 1 – *Profiling*: the instructional design process began with the definition of the lesson's core objectives, namely, to enhance and assess students' spatial and sociocultural awareness of urban transformation processes, with a particular focus on Milan's Chinatown. A secondary aim was to foster critical reflection on multicultural integration and community identity through immersive media. Given the interdisciplinary context, it was crucial to tailor the experience to students with varying degrees of familiarity with XR technologies and urban geography.

   Professor M. shared detailed information about the distribution of students across two campuses (Milan, Piacenza and Brescia) with approximately 20–30 university students that could participate in the MetaLab. He also provided the planned didactic outings, and the existing infrastructure available (e.g., PowerPoint, analog tools, and online polling platforms). From this baseline, we identified a core learning goal: enabling students to explore the multicultural dynamics and diachronic evolution of the Chinatown district in Milan. The lesson aimed to cultivate spatial intelligence, cultural awareness, and critical observation, rooted in the Education for the Territory (EaT) methodology.

   The professor also expressed interest in comparing three different modes of educational immersive, semi-immersive, and real-world outings, to evaluate their respective impacts on student engagement and learning. Given the interdisciplinary composition of the student cohort, the MetaLab should have been tailored to learners with heterogeneous backgrounds, including different levels of digital literacy, prior familiarity with XR, and knowledge of urban geography. This first meeting provided a clear pedagogical foundation, outlining the knowledge areas, skills, and competences to be addressed, and ensured a shared vision to guide the subsequent design phases.

2. Meeting 2 – *Consolidation*: during the second co-design meeting, the design of the experience was consolidated into a tri-modal instructional format comprising: (i) an immersive MetaLab (Milan), (ii) a non-immersive MetaLab (Online/ Brescia), and (iii) an in-person Urban Walk (students from Piacenza coming to Milan) with real-world geographic data collection in Milan Chinatown. The rationale behind this choice was twofold.

   On the one hand, it responded to practical and pedagogical needs: the distribution of students across campuses required parallel learning pathways that could guarantee equitable access to the same instructional content, while also ensuring flexibility and inclusivity in relation to technological conditions, varying levels of XR familiarity, and accessibility needs. On the other hand, the tri-modal design was conceived as a deliberate research strategy, allowing for a systematic comparison of the same learning experience across three different modalities, immersive, semi-immersive, and real-world. In this way, the project not only addressed contextual constraints but also created an opportunity to investigate how different modes of delivery shape engagement, spatial awareness, and critical reflection on multicultural urban dynamics.

   The meeting also addressed technical logistics, student accessibility, and classroom management. Particular attention was paid to designing an inclusive experience: providing alternatives for students with motion sickness or sensory limitations, preparing paper-based quizzes, and ensuring multi-modal delivery of content.

   Several XR modalities were initially examined as potential options for structuring the learning experience. These included: (i) fully immersive experiences with Spatial.io accessed through Oculus Quest headsets, enriched with 3D objects and virtual walkthroughs; (ii) semi-immersive solutions such as Google Earth VR, 360° videos, and EarthQuest, designed to provide remote students in Brescia with an alternative yet comparable experience; and (iii) in-person exploration of the Chinatown district in Milan for students coming to Piacenza, allowing students to collect real-world geographic data.

   The pedagogical scenario was structured around a shared narrative and common instructional activities, ensuring that all students, regardless of modality, engaged with the same content. To enrich the design, proposals such as loci-based memory strategies, interactive quizzes, and spatial recall tasks were considered. Professor M. prepared a preliminary format with prompts, exploratory questions, and cognitive tasks aimed at stimulating students' geographic thinking, while the team planned a pre-lesson survey to map available devices and accessibility needs.

   The experience for all groups was designed to conclude with a guided discussion and a formative assessment involving mental mapping, comparative landscape analysis, and application of the EaT framework, identified as a core pedagogical objective of the MetaLab.

3. Meeting 3 – *Refinement*: during the final meeting, the MetaLab experience underwent internal prototyping to verify usability, technical functionality, timing, and narrative coherence before

classroom delivery. The team, led by the ILeaD, and the research group of Professor M. tested both the selected technologies and the narrative structure of the experience, ensuring that the storytelling was consistent and effectively supported the pedagogical objectives. The Wander-based exploration was mirrored across different devices, and feedback was collected on user navigation, activity sequencing, role distribution, and narrative flow.

Based on this feedback, adjustments were introduced to guarantee smooth transitions between phases (e.g., avatar-led exploration, group activities, and timing) and to reinforce the coherence of the virtual journey. The MetaLab was then implemented in the three modalities. Evaluation was conducted through formative feedback and structured questionnaires, focusing on student engagement, cognitive outcomes, and the perceived added value of XR-enhanced learning.

This case illustrates how the MetaLab model brings together pedagogical co-design, technological innovation, and immersive storytelling within a unified and scalable instructional format. The structured collaboration between faculty, the Immersive Learning Designer (ILeaD), and technical staff facilitated a close alignment between educational objectives and XR experience design, while the concluding debriefing supported both epistemic and emotional engagement, which represent key features of the MetaLab framework.

After outlining the workflow through which a MetaLab is conceived and developed, the next step is to present the methodology and measures employed to evaluate its implementation. This stage constitutes an integral part of the prototyping process, as the primary aim of the present dissertation was not only to design but also to conduct research on the effectiveness of the MetaLab model and the immersive laboratories themselves. Within this framework, the *Evaluation* phase served both as a research tool and as a practical mechanism to generate evidence on the impact of immersive learning. Moreover, while in this dissertation specific instruments and protocols were adopted to assess cognitive, emotional, motivational outcomes, the prototyping process allows for the identification and co-definition, together with university faculty, of additional measures tailored to specific pedagogical goals. In this way, evaluation is conceived not as a fixed procedure but as a flexible and participatory dimension of the MetaLab prototyping cycle.

2.4 MetaLabs General Workflow

The previous sections have illustrated how the second objective of this doctoral dissertation, namely, to develop an instructional model for immersive learning, the "MetaLab" framework, was addressed. Through the workflow outlined above, and with the active involvement of university faculty in the co-design process, a total of sixteen MetaLabs were created across different courses and disciplinary contexts. Having established the model and its practical implementations, the subsequent phase of the research focuses on testing, which requires a systematic reflection on how to evaluate the impact of immersive learning experiences on students' cognitive, social, and emotional engagement (third objective of the present doctoral work). The following section is therefore dedicated to describing the methodological approach adopted to assess students' experiences within the MetaLabs.

The flowchart (Fig. 18) illustrates the iterative workflow adopted for the design, implementation, and evaluation of the MetaLabs. The process begins with the planning phase, where the initial objectives and structure of the MetaLab are defined. This is followed by the co-design phase with ILeaD, in which faculty members collaborate with the research team to refine the pedagogical intentions and align them with the affordances of immersive technologies. Once a prototype is developed, the MetaLab testing stage determines whether the instructional design is ready to proceed. If the outcome is considered successful, the process continues with a pre-test, aimed at collecting baseline data from students prior to the immersive activity. If the test is unsuccessful, the workflow directs the process toward refinement, after which the revised MetaLab is reintroduced into the cycle.

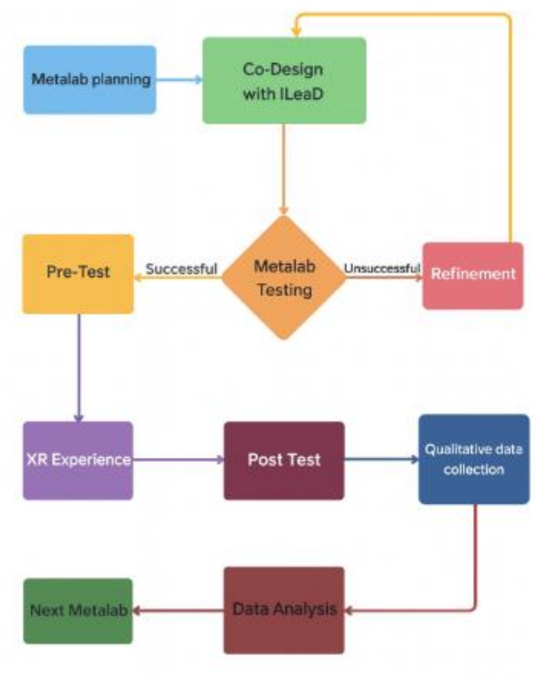


Fig. 18. Flowchart of the MetaLab assessment and implementation process.

When the design passes the testing stage, students participate in the XR experience, which represents the core of the learning activity. Afterward, a post-test is administered to capture changes in students' perceptions, engagement, and learning outcomes. In addition to the quantitative measures included in the pre- and post-test instruments, the workflow incorporates a dedicated step for qualitative data collection, which enables the capture of richer, more contextualized insights into learners' experiences. Although the present doctoral dissertation does not address qualitative analyses in detail, it is important to highlight that the workflow has been conceived to allow for mixed-methods research designs. In this sense, dimensions such as students' reflections, narratives, and collaborative interactions can be examined through interviews, focus groups, or observational data, thus complementing the quantitative assessment.

Finally, all collected data is subject to analysis, which informs the design of the next MetaLab and contributes to the continuous improvement of the framework. This cyclical structure underscores the iterative nature of the

MetaLab approach, in which design, testing, evaluation, and refinement are integrated into an ongoing process of innovation.

2.5 Students' Assessment Protocol

2.5.1 Rationale

The rationale guiding the development of the present evaluation protocol is deeply rooted in the theoretical perspective outlined in Section 2.1.1, "The Centrality of Experience in Immersive Learning", which positions *experience* as the primary unit of analysis for both instructional design and educational research.

As argued by Parrish, Wilson, and Dunlap (2011), instructional design should not merely focus on cognitive outcomes or the acquisition of discrete skills, but on the crafting of holistic, meaningful learning experiences that integrate cognitive, affective, social, and aesthetic dimensions. This perspective aligns with the broader vision of immersive learning as articulated by Riva, Gaggioli, and colleagues (2016), who conceptualize Virtual and Augmented Reality as *experience technologies*, tools capable of expanding perception, agency, and self-awareness through embodied, multisensory engagement.

In this view, evaluating immersive education requires assessing not only *what* students learn, but *how* they live and interpret their learning experiences. The MetaLab framework therefore positions experience, rather than technology, at the center of both design and evaluation. Consistent with the theoretical principles discussed in Chapter 2, the present protocol develops a quantitative, multidimensional way to capture the evolution of students' experiential states *before and after* participation in MetaLabs.

By administering validated self-report questionnaires before and after each MetaLab, the protocol captures how learners' perceptions, emotions, and engagement change as a result of the immersive experience, offering a dynamic understanding of learning as a process of transformation rather than as a static outcome. This pre–post approach enables the detection of shifts in students' presence, affective involvement, and technological acceptance, dimensions that, as demonstrated by Makransky and Lilleholt (2018) and Radianti et al. (2020), mediate learning effectiveness in immersive environments.

Importantly, the evaluation protocol received formal approval from the Ethics Committee of Università Cattolica del Sacro Cuore**,** ensuring adherence to ethical research standards in data collection and participant involvement. Following this approval, the protocol was systematically applied to all MetaLabs implemented during the 2024/2025 academic year, allowing for consistent and comparable assessment across diverse academic disciplines.

Within Chapter 3, Test & Evaluation Phase, three empirical studies illustrate its progressive application:

- *Test & Evaluation* Study 1 reports on two *pilot MetaLabs* conducted prior to the protocol's formal validation, serving as exploratory cases that informed its refinement.
- *Test & Evaluation* Studies 2 and 3 employed the *validated version of the protocol* to systematically assess students' pre–post learning experiences, generating empirical evidence on usability, emotional engagement, and continuance intention across diverse educational contexts.

2.5.2 Methods

Building on the proposed MetaLab framework, this section presents the research protocol implemented in several MetaLabs across diverse university courses and disciplinary areas.

2.5.2.1 Participants

Participants included university students who took part in the MetaLab activities. A total of 16 MetaLabs were co-designed and conducted during the a.y. 2024/2025 (*see* Chapter 3 for details about the developed MetaLabs).

2.5.2.2 Experimental Design

This protocol employes pre-post experimental design, to be conducted during the implementation of the MetaLabs.

2.5.2.3 Students' Assessment

Students completed two online surveys delivered on Qualtrics. All instruments that were not available in a validated version in Italian were translated using back translation (*see* Appendix II for all items).

At T0 (pre-MetaLab), one week before participation, students completed a survey including:

- *Sociodemographic data* (age, gender, academic field, year of study), to contextualize results across learner profiles.
- *Previous experience with VR* technologies, distinguishing between non-immersive (desktop-based) and immersive (head-mounted) systems, as prior familiarity can moderate presence and learning outcomes.
- *Pre-adoption attitudes*, assessed through the Extended Expectation-Confirmation Model (EECM) (Di Natale et al., 2024b).
- The *Inclusivity and Accessibility* Pre-Immersive Experience Questionnaire (see Section IV-D).

The EECM served as the central theoretical framework because it extends classic models of technology acceptance by capturing the full cycle from pre-use expectations to post-use confirmation, satisfaction, and continuance intention, while incorporating critical determinants such as perceived usefulness, effort expectancy, and self-efficacy. This makes the EECM especially suitable for evaluating immersive learning innovations: students enter MetaLabs with a priori beliefs about potential learning benefits and anticipated effort, then compare these beliefs with their lived experiences. Based on this comparison, they form judgments of satisfaction and, in interaction with perceived usefulness and self-efficacy, develop intentions to continue engaging with XR-based MetaLabs in the future. Constructs were thus assessed both before participation (performance expectancy, effort expectancy) and after participation (confirmation, satisfaction, perceived usefulness, self-efficacy, continuance intention). Higher expectancy values at T0 are hypothesized to predict higher confirmation and satisfaction at T1, while perceived usefulness and self-efficacy are expected to positively predict continuance intention.

In addition, the Inclusivity and Accessibility Pre-Immersive Experience Questionnaire assessed students' baseline perceptions of whether XR technologies are accessible and inclusive, covering adaptability to diverse needs, support for different learning styles, and usability for students with varying levels of familiarity or impairments. Responses were collected on Likert-type scales, with higher scores reflecting stronger inclusivity and accessibility. Including this measure ensured that the evaluation addressed not only performance and affective constructs but also broader concerns of equity and universal access, increasingly recognized as critical in immersive higher education (Ryan et al., 2021; Izouaouen et al., 2025).

At T1 (post-MetaLab), immediately after the MetaLab, students completed a second survey assessing eight dimensions:

- *Post-adoption attitudes* and continuance intention were measured through the EECM, including confirmation, satisfaction, perceived usefulness, self-efficacy, and intention to reuse, capturing how expectations were revised after participation.
- *Usability* was measured with the System Usability Scale (SUS; Brooke, 1996), a technology-agnostic, ten-item instrument widely used across domains. The SUS alternates positive and negative items, producing a score from 0 to 100, where 68 represents average usability and higher values indicate superior usability. In XR contexts, usability is a critical precondition for engagement, and higher SUS scores are expected to correlate with satisfaction and continuance intention in line with the EECM.
- *Sense of presence* was assessed using a validated single-item measure (Bouchard et al., 2004), which captures the subjective impression of "being there" in the virtual environment, one of the most central experiential variables in XR learning.
- *Epistemically related emotions* were measured using Pekrun's (2006) control-value theory of achievement emotions, which identifies affective states that emerge in knowledge-seeking processes, such as curiosity and surprise (typically facilitative of learning) as well as anxiety and frustration (potentially disruptive if excessive). These emotions are considered central in immersive contexts, where novelty and sensory richness can amplify both positive and negative emotional responses, directly influencing engagement and depth of processing.
- *Absorption* was measured with the Absorption subscale of the Psychological Flow Scale (Norsworthy et al., 2023). Absorption reflects deep attentional engagement and is a key component of flow theory (Csikszentmihalyi & Csikzentmihaly, 1990), hypothesized to indicate optimal alignment between technological affordances, task challenge, and instructional scaffolding. Higher absorption scores are expected to positively predict satisfaction, perceived usefulness, and continuance intention, if workload is not excessive.
- *Workload* was measured with three subdimensions of the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988): *mental demand, physical demand,* and *effort*. The NASA-TLX is a multidimensional measure of subjective workload widely used in human factors research. In XR, workload measures help distinguish between productive cognitive effort and overload that can undermine satisfaction and learning. Moderate scores may indicate deep engagement, whereas high

scores can predict frustration and lower satisfaction. Seventh, learning motivation was captured through ad hoc items designed to assess whether participation in the MetaLab increased students' interest in the subject matter (e.g., "I feel more motivated to learn this subject after participating in the MetaLab").

- *Perceived learning effectiveness* was assessed with items adapted from Lee and Tsai (2011), focusing on students perceived acquisition of knowledge and conceptual understanding.

This evaluation strategy integrated EECM for technology adoption and continuance, SUS for usability, presence for immersion, epistemically related emotions for affective engagement, absorption for attentional immersion, NASA-TLX for workload, and items on motivation, learning effectiveness, and inclusivity. By combining these theoretically grounded measures, the framework allowed us to capture not only *whether* students learned but also *how* they experienced the MetaLabs cognitively, emotionally, and motivationally, dimensions that constitute the central focus of this research.

2.5.3 Discussion

In summary, the proposed evaluation protocol provides a coherent and theoretically grounded structure for investigating how immersive learning environments influence students' experiences and perceptions. By translating the experiential principles of the MetaLab framework into measurable constructs, the protocol ensures methodological consistency, empirical rigor, and the possibility to compare results across diverse educational contexts.

2.6 Conclusions

This chapter has documented the *Prototype* phase of the doctoral project, moving from the insights generated during *Empathize* to the definition and operationalization of the MetaLab instructional design model and its first set of immersive laboratories (the MetaLabs). The chapter first situated MetaLab within the historical and theoretical lineage of Instructional Design (ID), from media-supported training and behaviorist/cognitivist traditions to contemporary constructivist and socio-cultural perspectives, arguing for ID as both science-based technology and creative design practice. Building on this foundation, it articulated the experiential and transformative orientation of MetaLab, detailing how experience, rather than technology per se, constitutes the central unit of analysis and design in XR-enhanced education.

Anchored to this stance, the chapter introduced the three guiding principles of the MetaLab model, facilitating epistemic/ personal transformation, cultivating epistemic emotions, and enabling creative collaboration and group flow, and showed how these principles concretely inform pedagogical scenarios in XR. To ensure feasibility and contextual relevance in higher education, the chapter formalized the role of the ILeaD as a bridging profile across pedagogy, technology, and psychology, responsible for aligning learning goals with XR affordances, anticipating accessibility and inclusivity needs, and scaffolding faculty adoption and confidence.

Methodologically, the chapter detailed a structured, participatory workflow for co-design with university faculty, articulated in three meetings (i.e., Profiling, Consolidation, Refinement). This workflow translated the theoretical principles into actionable design decisions and classroom-ready prototypes. Through this process, sixteen MetaLabs were co-created and implemented across diverse courses and disciplinary contexts (*see* Chapter 3).

The *Prototype* phase therefore accomplished three intertwined outcomes: (i) it consolidated MetaLab as an instructional design framework grounded in established theory and empirical user research; (ii) it operationalized the framework into concrete, inclusive, and scalable XR learning experiences; and (iii) it established the organizational and human infrastructure (ILeaD and collaboration with faculty members) necessary for sustainable curriculum integration. Importantly, the MetaLabs created in this phase serve as the empirical substrate for testing whether the theorized mechanisms (e.g., presence, epistemic emotions, absorption, group flow) translate into measurable outcomes (e.g., usability, engagement, perceived usefulness, inclusivity, continuance intention) under real instructional constraints. The transition from *Prototype* to *Testing & Evaluation* thus marks a shift in the primary research question, from *how* to design (i.e., principles, roles, workflows) to *what* effects the designs produce (e.g., learning, motivation, user experience, adoption).

3. Test and Evaluation Phase: MetaLab Implementation and Assessment

The present chapter introduces the third phase of the doctoral project, *Test and Evaluation* (Fig. 19), which focuses on the empirical implementation and systematic assessment of the MetaLab framework within authentic higher education contexts. This phase specifically addresses the third objective of the doctoral research, namely, to evaluate the impact of MetaLab-based learning experiences on students' cognitive, social, and emotional engagement.

Building on the results of the preceding *Prototype* phase, the *Test and Evaluation* phase involved the delivery of co-designed immersive learning modules (i.e., MetaLabs) across diverse university courses, followed by the assessment of their experiential and psychological effects on students. The implementation was carried out during the 2024–2025 academic year.

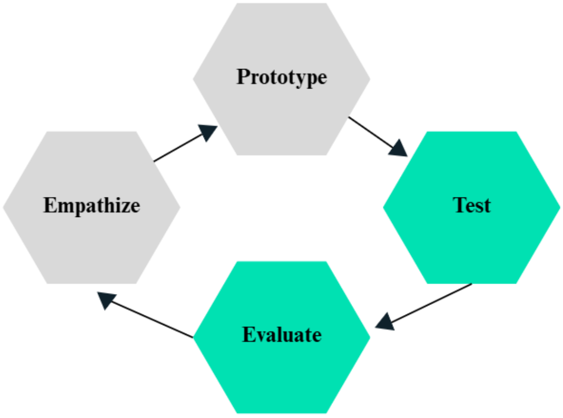


Fig. 19. Current stage of the doctoral process.

From a methodological standpoint, this phase directly reflects the iterative logic of Design-Based Research and the reflective cycles of Design Thinking that underpin the present work (*see* Methodology Section in the Introduction). Within the DBR paradigm, *Test* and *Evaluation* correspond to the *Implementation* and *Evaluation* components of the ADDIE model (Kurt, 2017), which are conceptually distinct yet operationally intertwined. Implementation concerns the actual delivery of designed learning interventions in real university settings, while evaluation is embedded throughout this process as a continuous mechanism for collecting, interpreting, and responding to evidence about learning effectiveness, usability, and engagement.

As highlighted in the introduction, evaluation in ADDIE unfolds through formative and summative dimensions that interact dynamically (Tessmer, 1993; Reeves, 2006; McKenney & Reeves, 2018; Beahm & Bradshaw, 2023). *Formative evaluation* occurs during implementation through activities such as classroom observation, usability testing, and student feedback, allowing real-time adjustments to improve learning flow and user experience. *Summative evaluation* follows implementation, assessing broader learning outcomes, satisfaction, and scalability (Gustafson & Branch, 2002). Together, these two forms create a reflective feedback loop, ensuring that implementation provides the empirical ground for evaluation, and that evaluation, in turn, informs iterative refinement and theoretical generalization.

At the same time, within the Design Thinking framework, this phase parallels the *Test* stage of the Stanford d.school model (Stanford, 2010; Brown, 2008), where prototypes are implemented and iteratively refined based on user feedback and real-world observation. The objective is not merely to confirm the success of the instructional design framework that led to the learning experiences, but to understand how end users - in this case, university students - interact with XR technologies and how immersive learning experiences affect their emotions, perceptions, and cognitive processes. In this context, testing becomes a moment of inquiry, transforming prototypes into empirical evidence and deepening understanding of how immersive technologies can meaningfully support education.

In this Chapter, this theoretical and methodological integration was operationalized through three empirical studies, each combining *Test* and *Evaluation* in parallel. In these studies, MetaLabs were implemented within real university courses and systematically examined through pre- and post-measurements of key psychological constructs, including engagement, presence, cognitive load, epistemic emotions, and perceived learning. This approach allowed both to measure the effectiveness of immersive learning interventions and to explore the subjective dimensions of students' experiences in depth.

The first study focused on two MetaLabs integrated into a master's course, exploring students' social, cognitive, and affective responses. This investigation provided an in-depth understanding of how immersive environments support social presence, manage cognitive load, and stimulate epistemic emotions. The second study broadened the scope by analyzing sixteen MetaLabs across different disciplines and campuses, evaluating usability, perceived effort, and continuance intention as determinants of sustainable XR adoption in higher education. Finally, the third study concentrated on learning effectiveness, triangulating quantitative outcomes with students' qualitative reflections to assess perceived learning gains and the pedagogical value of MetaLabs. As it will be discussed, these three studies move from a fine-grained examination of individual experiences to a broader analysis of scalability and educational impact.

3.1 Test and Evaluation Study 1: Social, Cognitive, and Affective Experience in Two MetaLabs

In line with the objectives of the *Test and Evaluation* phase, this study investigated how university students experienced immersive learning across *social, cognitive, and affective* dimensions within MetaLab sessions implemented in an authentic higher education context. Two MetaLabs have been implemented as part of the course *VR Techniques and the Metaverse for Well-being* and have been designed according to the MetaLab framework (*see* Chapter 2) and implemented through immersive VR technology on a metaverse platform (i.e., Spatial.io). The outcomes of this work have been reported in a scientific publication[10] that is currently under review.

3.1.1 Theoretical Background

Among XR technologies, Immersive Virtual Reality (IVR) has emerged as a powerful tool for education (Di Natale et al., 2020; Jensen & Konradsen, 2018; Marougkas et al., 2023; Pellas, Mystakidis & Kazanidis, 2021; Poupard et al., 2025; Radianti et al., 2020). Most research and educational applications of IVR technologies focus on individual learning experiences, where students interact with virtual environments either through non-immersive (desktop or mobile-based) or immersive (head-mounted displays) systems. These applications are widely used in science, medicine, engineering, and skill-based training, enabling hands-on learning in simulated settings.

Beyond individual learning, IVR has evolved into social and collaborative learning spaces (van der Meer et al., 2023). In this context, *Social Virtual Reality (VRS)* platforms garnered particular attention due to

[10] Di Natale, A. F., Bartolotta, S., Riva, G., Malighetti, C., Gaggioli, A., & Villani, D. (2025). Social, cognitive, and affective experiences during immersive virtual reality laboratories (MetaLabs): Two descriptive cases among university psychology students. Unpublished manuscript, Department of Psychology, Università Cattolica del Sacro Cuore, Milan, Italy.

their capacity to merge immersive environments with interactive and collaborative learning (Chessa & Solari, 2021; Mystikadis et al., 2021). These platforms create shared virtual spaces where users interact through avatars facilitating real-time communication and collaboration and allowing students to engage in role-playing, simulations, or group problem-solving tasks. This expands the traditional boundaries of learning by enabling new ways of knowledge construction that leverage both social and experiential dimensions. To fully understand the potential of virtual social platforms in educational contexts, it is crucial to consider how these technologies impact key psychological dimensions that shape the learning process: social, affective, and cognitive.

The *social dimension* refers to the extent to which learners feel connected to others within an educational environment. A key aspect of this dimension is *social presence*, which encompasses both the perception of co-presence, that is being in the same space as others, and the deeper sense of personal connection and psychological proximity, often described in terms of intimacy and immediacy (Kreijns, Xu & Weidlich, 2022). Social presence is a central aspect to consider when learning takes place on VRS platforms. In these platforms, whether students are remote or co-located, their interactions occur in an online environment, which is fundamentally different from traditional face-to-face setting. Research on online learning has highlighted challenges in maintaining social presence, particularly due to the absence of physical cues and the lack of a shared physical space. However, much of this research has primarily focused on conventional platforms, such as videoconferencing, which may limit the depth and quality of social interaction due to reduced nonverbal communication, spatial awareness, and embodied engagement (Di Natale et al., 2024a).

In contrast, IVR environments have the unique potential to overcome these limitations and foster higher levels of social presence (Makransky & Petersen, 2021). Even though participants engage online, VRS platforms enable interactions within a shared virtual space, where communication occurs through embodied avatars which can replicate nonverbal cues, gestures and spatial dynamics. This allows participants to experience a heightened sense of co-location and makes interactions feel more natural and intuitive, akin to being in the same physical room. Studies have shown that participants in IVR environments experience a heightened sense of being "together" with others compared to traditional online settings (Barreda-Angeles et al., 2023; Ozonour et al., 2018; Steinicke et al., 2022; Yilmaz et al., 2016) and more comparable to traditional face-to-face settings (Smith & Neff, 2018; Uhl et al., 2023). This heightened sense of co-presence in IVR creates an ideal setting for promoting collaboration, which in turn reinforces social presence in a reciprocal relationship (Johnson & Johnson, 2009).

The *cognitive dimension* focuses on how learners engage with educational content and process information. Cognitive load refers to the mental effort required to process information and must be carefully managed to avoid overwhelming learners (Sweller, 2005). It comprises three components: (i) intrinsic load (the effort directly related to the complexity of the learning task); (ii) extraneous cognitive load (effort imposed by how the information is presented), and (iii) germane cognitive load (effort related to integrating new information with existing knowledge or developing strategies for problem-solving).

According to the Multimedia Learning Theory, students' cognitive load is deeply influenced by the way information is presented (Mayer & Moreno, 2003). In this context IVR present challenges in properly managing cognitive load, especially *extraneous cognitive load* (Meccawy, 2022; Poupard et al., 2025). Poorly designed IVR environments can inadvertently introduce unnecessary distractions, such as overly complex interfaces, irrelevant visual or auditory stimuli, or an overwhelming number of interactive elements (Skulmowski & Xu, 2022) that can overwhelm learners, especially novices, leading to cognitive overload (Frederiksen et al., 2020; Frithioff et al., 2020; Makransky et al., 2019; Parong & Mayer, 2021a; Parong & Mayer, 2021b). These distractions can impair learning outcomes and disrupt learners' concentration, diverting their focus of attention away from the primary learning task, negatively impacting their ability to learn effectively (Skulmowski & Xu, 2022). To mitigate these issues, strategies such as minimizing visual complexity (Rettinger et al., 2024) and employing the segmentation principle (Kilngenberg et a., 2023; Parong & Mayer, 2018), breaking content into manageable, smaller sections, are essential to prevent learners from becoming overwhelmed and optimizing cognitive resources.

The *affective dimension* involves the emotional experiences that learners go through during the learning process (Pekrun, 2006). *Epistemic emotions*, such as curiosity, surprise, confusion, and frustration, can significantly impact learning processes and outcomes (Arguel et al., 2018; Muis, Chevrier & Singh, 2018). VRS platforms offer promising opportunities for experience-based active learning and the cultivation of positive epistemic emotions, such as curiosity as they offer interactive environments and inquiry-based hands-on activities that encourage active exploration, experimentation, and discovery (Alnagrat et al., 2022; Gaggioli et al., 2024; Taheri & Aguayo, 2022). Unlike traditional videoconferencing platforms, which may limit emotional engagement due to passive content delivery and reduced interactivity, IVR enables learners to immerse themselves in dynamic, participatory learning experiences, enhancing emotional involvement in the educational process. Although research on the emotional impact of VRS platforms is still emerging, recent studies comparing them to traditional videoconferencing platforms suggest that virtual environments elicit higher levels of positive affect (Lønne et al., 2023; Olmos-Raya et al., 2018) even when accessed through non-immersive desktop setups (Di Natale et al., 2024a). However, it is equally important to recognize that these technologies can also provoke negative emotions, such as frustration, particularly if the activities are overly complex or not sufficiently intuitive. Managing this emotional balance is critical to optimizing VR learning environments and ensuring that they support, rather than hinder, the learning process.

To truly understand IVR technologies and VRS platforms learning potential, educators must consider a structured framework to identify the key points and priorities of the educational experience that align with the social, cognitive, and emotional dimensions of the learning experience. Studies have shown that well-designed IVR pedagogical experiences can balance immersion, cognitive engagement, and structured pedagogy, ensuring that learners not only feel present in the environment but also develop meaningful skills and knowledge (Keskitalo & Saukkoriipi, 2025; Paulsen et al., 2024). This reinforces the idea that IVR learning should not rely solely on the novelty of technology but should be embedded in a structured pedagogical framework that prioritizes learning outcomes over technological fascination.

3.1.2 Research Objectives

While the possibilities seem boundless, it is important to recognize that the current integration of IVR technologies into educational curricula remains limited as most scientific studies conducted so far have been experimental in nature, and only a few were applied to real curricular settings (Han et al., 2022). Educational institutions and researchers are actively exploring whether the integration of VR technologies is not only feasible but also pedagogically effective. This study contributes to the field by moving beyond controlled experimental setups and examining VRS platforms within an actual university course, in which two MetaLabs were offered. Unlike prior research that often focuses on isolated cognitive or technical aspects, this study takes a holistic approach, investigating the social, cognitive, and affective dimensions of collaborative learning in IVR.

The objectives were to investigate: (i) the overall quality of students' learning experiences and (ii) individual variations in social, cognitive, and emotional responses. Specifically, we:

- Measure students' perceptions of *social presence*, assessing whether two selected MetaLabs (*see* description below) elicited comparable social experiences and exploring individual-level variability to identify patterns in how participants perceived social presence across the two sessions.
- Describe students' levels of perceived *extraneous cognitive load* and *concentration*, evaluating whether the two MetaLabs were consistent in terms of managing cognitive demands and maintaining focus, and investigating individual-level variability to understand differences in participants' cognitive engagement.
- Describe students' emotional experiences in terms of *epistemic emotions*, evaluating whether the two MetaLabs elicited comparable emotional responses and examined whether students' overall emotional experiences were predominantly positive or negative.

By addressing these objectives, the study aimed to provide an overview of the psychological dimensions of learning within MetaLabs. Given the emerging nature of this field and the still limited availability of IVR devices in higher education, this research represents one of the first systematic attempts in the Italian context, and is aligned with recent initiatives conducted internationally, such as those at Stanford University (Han et al., 2023). In particular, this study builds upon and extends the current understanding of students' attitudes towards IVR in education (Di Natale et al., 2024b), by exploring the critical factors that shape learning experiences provided by these technologies. The objective is to provide institutions and educators with insights into the effective incorporation of VRS platforms into educational practices.

3.1.3 Methods

The study adopted a quantitative research design based on a structured self-report questionnaire administered at the conclusion of each MetaLab session. This pilot study was conducted prior to the formal validation of the evaluation protocol described in Section 2.5 and therefore did not employ it in its data collection and analysis procedures. Details about the measures used here are present in "3.1.3.3 Measures" paragraph.

Data collection was conducted anonymously and on a voluntary basis through the Qualtrics online platform. Participants were invited to complete the questionnaires immediately after the MetaLab activity to ensure accuracy of recall and to capture their direct impressions of the immersive learning experience. This timing was chosen to minimize retrospective bias and to preserve the ecological validity of participants' affective and cognitive responses.

All procedures complied with ethical research standards. The study protocol was reviewed and approved by the Ethics Committee for Research in Psychology (C.E.R.P.S.) at the Università Cattolica del Sacro Cuore, Milan, and conducted in accordance with the principles of the Declaration of Helsinki and institutional guidelines governing research involving human participants.

3.1.3.1 Participants

Participants were students enrolled in the course "*Virtual Reality Techniques and the Metaverse for Well-being"*, part of the Master's Degree Program in *Psychology of Well-being* offered by the Department of Psychology at the Università Cattolica del Sacro Cuore (Milan, Italy). All students attending the course were invited to take part in the study.

Of the 30 students enrolled, 27 agreed to participate, completing both MetaLab sessions and the corresponding pre- and post-experience questionnaires. The sample consisted primarily of female students, with an average age of 24.44 years (SD = 3.26). Participants reported varying levels of prior experience with immersive virtual reality (IVR) and social virtual reality platforms (VRSP). Detailed demographic and experiential information are presented in Tab. 9.

Tab. 9. Description of the sample

***M*Age (*SD*Age)**	24.44 (3.26)
Sex	
	Females: 19
	Males: 8
	Prefer not to say: 0
IVR experience*	
	Never: 3
	Rarely (once or twice): 13
	Sometimes (but non regularly): 7
	Often: 1
	Every day: 0
VRSP experience*	
	Never: 15
	Rarely (once or twice): 6
	Sometimes (but non regularly): 3
	Often: 0
	Every day: 0

** Note: one participant did not fill in the experience section of the questionnaire*

3.1.3.2 The MetaLabs Structure and Co-Design Process

Following the MetaLab design workflow outlined before (*see* Section 2.3.1), the development of the MetaLabs analyzed in this study was carried out through a structured co-design process involving university faculty, the ILeaD, and the research team. This process adhered to the three-step methodology previously described: (i)

Profiling, aimed at the identification of learning goals and contextual analysis; (ii) *Consolidation*, aimed at co-designing the learning experience, and (iii) *Refinement*, aimed at implementing the prototype of the experience and refining it, ensuring continuity with the pedagogical, methodological, and technological principles established during the Prototype phase (Fig. 20).

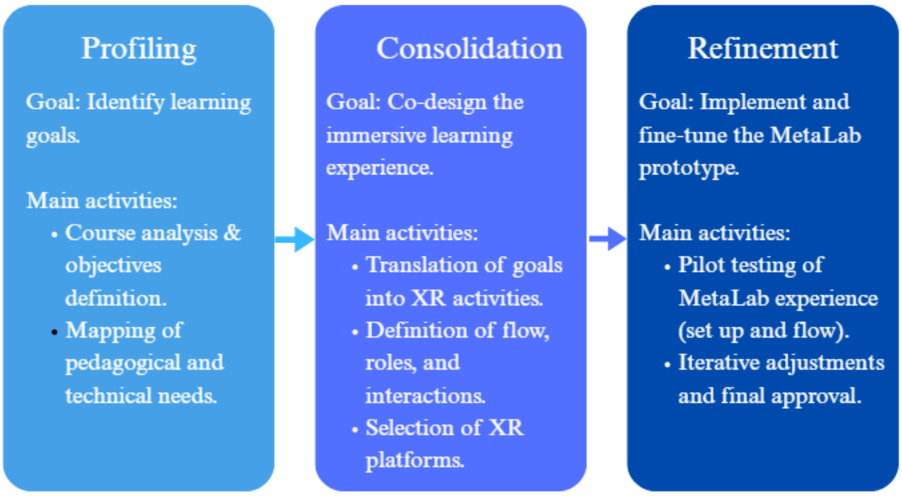


Fig. 20. MetaLab co-design process across three phases.

By applying this workflow, two MetaLabs were designed in close collaboration with the course instructor to align XR activities with curricular objectives, learner needs, and contextual constraints. This participatory approach guaranteed that the resulting immersive experiences were both pedagogically meaningful and technologically feasible, maintaining coherence with the theoretical and methodological foundations of the MetaLab framework.

Profiling

During the first co-design meeting, the instructor provided the research team with an overview of the course, outlining the learning objectives and explaining the course structure. To provide context, the course "Virtual Reality and Metaverse for Well-being" was created to help students develop an understanding of how VR can transform human communication, with applications in well-being, interpersonal interaction, and psychological rehabilitation. The course is offered within the Faculty of Psychology and specifically addresses students in this field.

Based on this premise, it was decided to design and implement two MetaLabs within the same course to explore distinct yet complementary facets of well-being through immersive learning. This choice aligned with the course's dual pedagogical goals: (i) to enable students to experience how immersive technologies can support self-awareness and embodiment processes, and (ii) to investigate how they can stimulate creativity and collaborative meaning-making.

Accordingly, the first MetaLab, *Embodiment MetaLab*, was designed to address the topic of embodiment techniques for addressing body image distortions, offering students a direct, immersive understanding of what embodiment entails. The second MetaLab, *Creativity MetaLab*, provided a first-person creative experience, allowing students to engage in interactive and collaborative activities to explore the role of creativity in promoting well-being.

Together, these two MetaLabs were intentionally conceived as complementary learning experiences, enabling students to engage with core theoretical themes of the course from both experiential and reflective perspectives, while allowing the research team to assess the consistency and variability of students' social, cognitive, and affective experiences across different immersive learning scenarios.

Consolidation

During the second co-design meeting, the research team and the course instructor collaboratively worked on the pedagogical structure and practical implementation of the MetaLabs. The meeting was organized as a design workshop aimed at translating the learning objectives of the course into concrete immersive learning activities, aligning technological affordances with the targeted psycho-pedagogical outcomes.

The group engaged in a collaborative ideation phase, using brainstorming, scenario mapping, and low-fidelity storyboarding. Various XR modalities were considered and evaluated based on criteria of pedagogical relevance, usability, and accessibility. The discussion led to the selection of immersive virtual reality headsets (i.e., Oculus Quest 2) combined with the social VR platform Spatial.io which was deemed suitable for supporting both individual and collaborative learning activities in a shared virtual environment.

The learning format was then defined through iterative discussion, resulting in a structured yet flexible session design applied consistently to both MetaLabs. Each MetaLab followed a three-step progression: (i) individual task, (ii) pair-based task, and (iii) group-based tasks, intended to gradually foster autonomy, collaboration, and collective reflection. This experiential sequence was followed by a guided debriefing and a short lecture-based consolidation phase, in which theoretical frameworks were reintroduced to anchor immersive activities to the course's academic content (Fig. 21).

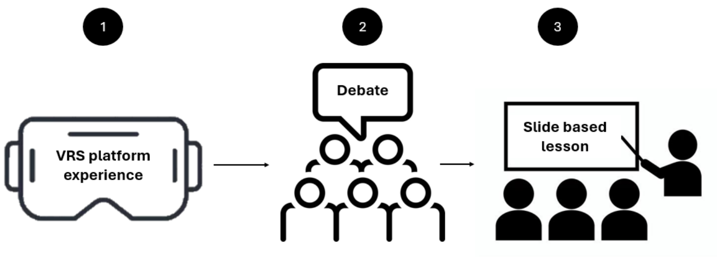


Fig. 21. MetaLabs Format

More specifically, the Embodiment MetaLab (Fig. 22) focused on using embodiment techniques in IVR to foster a positive body image. To facilitate students' understanding of the concept of embodiment, the immersive experiential session comprised three tasks: (i) an *individual* embodiment task; (ii) a *paired* embodiment task; (iii) a *group* embodiment task.

In the *individual* embodiment task, students were asked to replicate movements demonstrated by the instructor, thus promoting a closer identification with their virtual avatars. In the *paired* embodiment task, students were asked to create dyads and perform a mirror activity, namely, to mimic each other's actions, to explore the possibility of embodying another body. In the *group* embodiment task, students were asked to navigate and understand the spatial dynamics and boundaries associated with one's virtual body.

		
Individual embodiment task	*Paired* embodiment task	*Group* embodiment task

Fig. 22. The « Embodiment » MetaLab

The Creativity MetaLab (Fig. 23) focused on creativity and its application for wellbeing. The practical session will encourage students into a dynamic exploration of creativity, replicating the same format as the Embodiment MetaLab, with three tasks: (i) an *individual* creativity task; (ii) a *paired* creativity task; (iii) a *group* creativity task. For each task, students were asked to use a 3D pen[11] present in the virtual environment.

In the *individual* 3D pen task, students were asked to follow the instructor's demonstration and use the 3D pen for personal experimentation and artistic expression, thus fostering exploratory making and individual creative choices. In the *paired* 3D pen task, students were asked to form dyads and, using the 3D pen and complementary tools, collaboratively craft an artifact that symbolized their journey through the course, namely, to negotiate, combine, and materialize each other's ideas in a shared object, thereby facilitating meaningful dialogue and mutual reflection. In the *group* 3D pen task, students were asked to take part in a collective gallery walk to explore and discuss their creations, promoting shared reflective dialogue and communal sense-making.

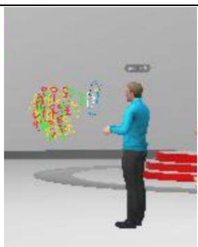
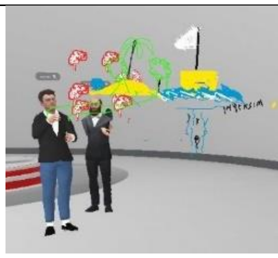
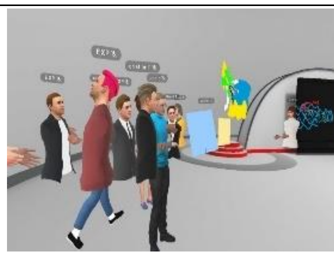
		
Individual creativity task	*Paired* creativity task	*Group* creativity task

Fig. 23. The « Creativity » MetaLab

[11] The 3D pen tool available in *Spatial* allows users to draw directly in three-dimensional space within a shared virtual room. Operated through standard VR controllers, it enables the creation of lines and shapes that remain anchored in the environment, with adjustable color and stroke width settings. The tool follows familiar VR interaction conventions, making it intuitive for users experienced with headset controllers. In multi-user sessions, drawings appear in real time for all participants, facilitating collaborative creation, visual communication, and shared reflection during group activities.

Although the two MetaLabs had different learning objectives (i.e., embodiment in the first and creativity in the second), they were deliberately designed to elicit similar user experiences. This intentionality stems from MetaLab's broader aim to provide students with learning experiences that holistically support their educational journey, considering the interconnected social, cognitive, and affective dimensions of learning. By engaging in these carefully curated activities, we aimed to elicit social presence, reduce extraneous cognitive load and promote concentration on the learning task, and foster positive emotions (Tab. 10).

Tab. 10. Key dimensions, constructs and design elements of the MetaLabs

Dimension	Construct	MetaLab Design
Social	Social presence	Students interacted through *embodied avatar*s in a *shared virtual space* where they completed *collaborative tasks*.
Cognitive	Extraneous cognitive load Concentration	Students were immersed in a *minimal virtual environment* with few distractions and completed three *segmented tasks*.
Affective	Epistemic emotions	Students engaged in *hands-on tasks* that encouraged *exploration* and *self-expression*.

Refinement

The final meeting of the MetaLab workflow was aimed at ensuring the effectiveness and feasibility of the learning experiences prior to their implementation in the course. During this meeting, the design and research team conducted a pilot session to evaluate the selected XR technologies, content, and tasks for both MetaLabs, by involving a small group of research assistants and the course instructor.

The research assistants provided feedback on the clarity of instructions, the functionality of the IVR equipment, and the overall flow of the session. The focus was on identifying potential technical issues, such as connectivity problems within the VRS platform, glitches in the Spatial environment, or hardware limitations (e.g., headset comfort and usability). The pacing of the sessions was also evaluated, ensuring that participants had sufficient time to complete each activity without feeling rushed. Meanwhile, the instructor assessed the alignment of the tasks with the learning objectives to ensure that the activities effectively supported the educational goals of the course.

3.1.3.3 Measures

Students who agreed to participate in the study were invited, as part of the course activities, to take part in both MetaLabs designed for the module. Their participation was voluntary and took place during regular class sessions to ensure ecological validity and minimize disruption to the course schedule.

After providing informed consent, participants were asked to complete three online questionnaires administered via Qualtrics: (i) a pre-MetaLab questionnaire, completed before the start of the two MetaLabs to collect baseline data; (ii) a post-MetaLab questionnaire following the *Embodiment MetaLab* session; and (iii) the same post-MetaLab questionnaire following the *Creativity MetaLab* session. These questionnaires were designed to capture changes in students' perceptions and experiences across the two immersive learning activities.

Pre-Metalab Questionnaire

This initial survey collected the following data:

- *Sociodemographic information*, including age and sex.
- *Prior IVR experience*. Participants were asked to indicate the frequency of their prior engagement with immersive IVR environments (e.g., headsets) using a five-point Likert scale (1: never; 5: everyday). Participants also reported their familiarity with VRS platforms (e.g., Spatial, Engage VR) on the same five-point scale. Table 1 above provides a detailed summary of participant responses across these measures.

Post-Metalab Questionnaire

This questionnaire, presented after each MetaLab, included measures of different social, cognitive and affective aspects of their learning experience:

- *Social presence*: Social presence was assessed using the 3-item subscale of the Multidimensional Presence Scale (Makransky, Lilleholt & Aaby, 2017). The items were translated into Italian using the back-translation method and have been previously used in similar studies (Di Natale et al., 2024a). Internal consistency was good in both MetaLabs (Embodiment α = 0.71, Creativity α = 0.74)
- *Extraneous cognitive load*: Extraneous cognitive load was measured using the scale developed by Parong and Mayer (2021a). This scale evaluates the extent to which participants perceived unnecessary or irrelevant distractions during the learning tasks. Internal consistency was good in both MetaLabs (Embodiment α = 0.77, Creativity α = 0.81)
- *Concentration*: Concentration on the task was measured using ad-hoc items adapted from the concentration sub-scale of Flow State Scale validated in Italian (Diana et al., 2012). These items focused on the extent to which participants felt fully absorbed in the activities and maintained focus throughout the MetaLab experience. Internal consistency was acceptable in both MetaLabs (Embodiment α = 0.60, Creativity α = 0.61)
- *Epistemic emotions*: Epistemic emotions were measured using the 21-item Epistemically Related Emotion Scales (Pekrun et al., 2017). This instrument evaluates seven distinct emotions: three positive (i.e., surprise, curiosity, enjoyment) and four negatives (i.e., confusion, anxiety, frustration, boredom), with each emotion assessed using three descriptive adjectives. The items were translated into Italian and verified using the back-translation method to ensure accuracy and equivalence and have been previously used in similar studies (Di Natale et al., 2024a). Internal consistency was acceptable to good for each emotion in both MetaLabs: surprise (Embodiment α = 0.78, Creativity α = 0.84), curiosity (Embodiment α = 0.60, , Creativity α = 0.76), enjoyment (Embodiment α =

0.60, Creativity α = 0.70), confusion (Embodiment α = 0.77, Creativity α = 0.85), anxiety (Embodiment α = 0.76, Creativity α = 0.79), frustration (Embodiment α = 0.78, Creativity α = 0.79), boredom (Embodiment α = 0.67, Creativity α = 0.67).

3.1.3.4 Data Analysis

Data analysis was designed to address the study's objectives by characterizing overall student experiences, comparing results across the two MetaLabs, and examining individual-level variability. Different analytical approaches were applied according to the specific research objectives.

For the first (O1) and second (O2) objectives, which focused on the social and cognitive dimensions, descriptive statistics were used to summarize and illustrate the main features of the collected data. Measures of central tendency (means, medians) and dispersion (standard deviations, frequencies) were calculated to provide a comprehensive overview of participants' experiences across the two MetaLabs. Particular attention was given to the theoretical midpoint of each scale (e.g., 3 on a 5-point Likert scale) to determine whether participants' responses indicated generally positive or negative perceptions. This approach is consistent with established practices in educational research, which recommend interpreting learners' subjective evaluations relative to neutral benchmarks (Georgiou, Tsivitanidou & Ioannou, 2021; Huang, 2011; Huerta et al., 2017; Li et al., 2023).

To assess the degree of similarity between the two MetaLabs, the *overlapping index* (η) proposed by Pastore and Calcagni (2019) was employed. This non-parametric measure quantifies the extent to which the distributions of key variables, such as social presence, extraneous cognitive load, concentration, and emotions, overlap across participants. Unlike descriptive statistics alone, the overlap index allows for a more granular assessment of the consistency of participants' experiences, providing insight into whether the two MetaLabs elicited comparable learning conditions.

Additionally, scatterplots were used to visualize individual trends in participants' responses across the two MetaLabs.

For the third objective (O3), focused on the affective dimension, descriptive statistics were again applied following the same analytical logic, complemented by radar charts to visually represent students' emotional profiles. This visualization enabled a clear comparison between positive and negative epistemic emotions reported in the two MetaLabs, offering a holistic perspective on the emotional components of immersive learning experiences.

3.1.4 Results

The results of the study are presented according to the three dimensions outlined in the research objectives: social, cognitive, and affective. Each subsection reports the findings for one dimension, combining descriptive and graphical analyses to provide both an overall and individual level understanding of students' experiences during the two MetaLabs.

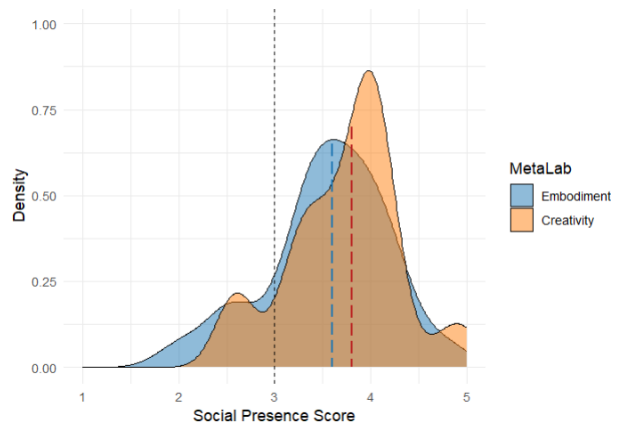
3.1.4.1 Social dimension

Social presence scores for both MetaLabs were summarized using measures of central tendency, dispersion, and distribution characteristics (Tab. 11).

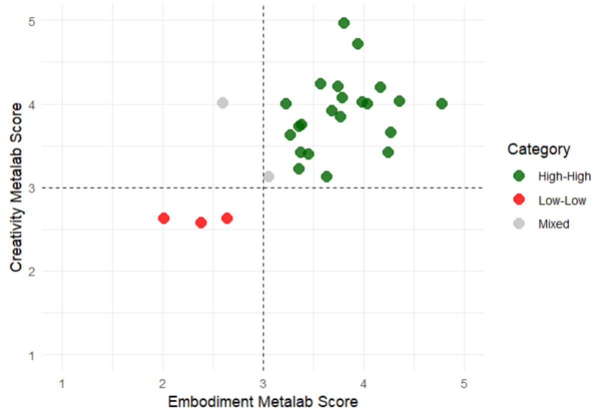
Tab. 11. Social dimension - Descriptive data and overlap index of the two MetaLabs

		Percentiles					
	mean (sd)	*25*	*50*	*75*	*sk*	*kur*	*η*
Social Presence							
Embodiment MetaLab	3.55 (0.64)	3.30	3.60	4.00	-0.52	3.09	0.87
Creativity MetaLab	3.73 (0.82)	3.40	3.80	4.00	-0.20	3.05	

Participants generally reported moderate to high levels of social presence, with mean scores above the theoretical midpoint of 3 on a 5-point Likert scale for both the Embodiment MetaLab (M = 3.55, SD = 0.64) and the Creativity MetaLab (M = 3.73, SD = 0.59). These results suggest that participants consistently felt a sense of connection and co-presence during the sessions. The distributions of social presence scores for the two MetaLabs were strikingly similar, as confirmed by the overlap index (η = 0.87). This indicates that despite differences in content and focus, the MetaLab design effectively fostered comparable levels of social presence across sessions (Fig. 24_a).



a. Social presence scores distribution
The density plot shows the distribution of social presence scores for the Embodiment (blue) and Creativity (orange) MetaLabs. The dashed vertical black line at a score of 3 represents the theoretical midpoint of the scale. The blue and red dashed lines correspond to the median values of social presence scores for the MetaLabs.



b. Individual trends in social presence
This scatterplot displays individual social presence scores in the Embodiment MetaLab (x-axis) and Creativity MetaLab (y-axis), categorized into three groups: high social presence in both MetaLabs (high-high, green) low social presence in both MetaLabs (low-low, red) or different experiences in the two MetaLabs (mixed, gray).

Fig. 24. Social Presence Scores

To explore participants' consistency in reported social presence across the two MetaLabs, we categorized individuals based on their Embodiment MetaLab and Creativity MetaLab scores and visualized results through a scatterplot (Fig. 24_b). Participants were categorized into three groups: High-High (scores > 3 in both MetaLabs), Low-Low (scores ≤ 3 in both MetaLabs), and Mixed (scores > 3 in one MetaLab and ≤ 3 in the other). Most participants were consistently categorized as either High-High (n = 22) or Low-Low (n =

3), demonstrating stable perceptions of social presence across sessions. A smaller subset of participants fell into the Mixed category (n = 2), reflecting variability in their experiences.

3.1.4.2 Cognitive dimension

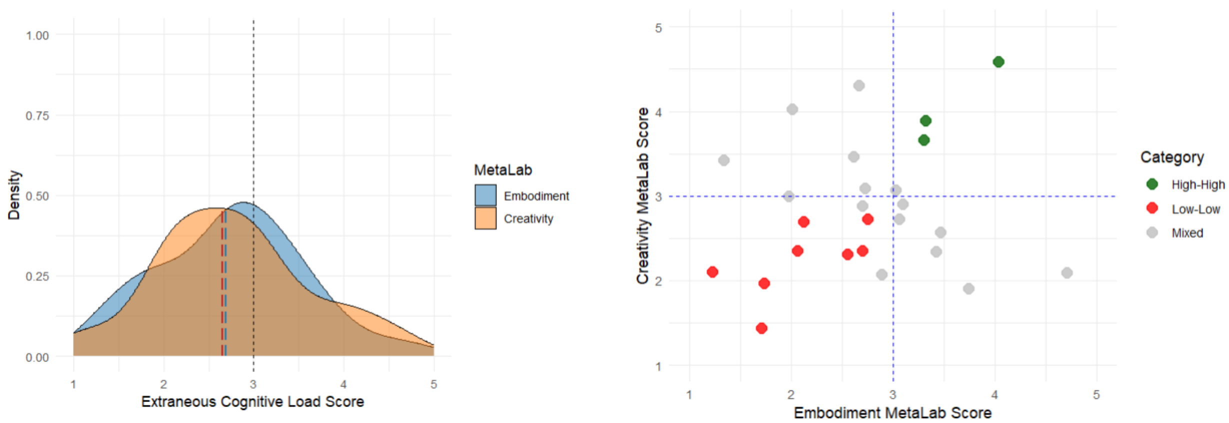
Extraneous cognitive load and concentration scores for both MetaLabs were summarized using measures of central tendency, dispersion, and distribution characteristics (Tab. 12).

Tab. 12. Cognitive dimension – Descriptive data and overlap index of the two MetaLabs

		Percentiles					
	mean (sd)	*25*	*50*	*75*	*sk*	*kur*	*η*
Extraneous cognitive load							
Embodiment MetaLab	2.74 (0.81)	2.00	2.67	3.33	0.14	2.74	0.90
Creativity MetaLab	2.76 (0.87)	2.16	2.67	3.16	0.28	2.80	
Concentration							
Embodiment MetaLab	3.74 (0.49)	3.50	3.75	4.00	-0.21	4.54	0.85
Creativity MetaLab	3.84 (0.44)	3.50	4.00	4.00	-0.45	3.33	

Participants reported low to moderate levels of extraneous cognitive load, with similar mean scores in the Embodiment MetaLab (M = 2.74, SD = 0.81) and the Creativity MetaLab (M = 2.77, SD = 0.87). The overlap index (η = 0.90) confirmed a high degree of similarity in cognitive load perceptions across both sessions (Fig. 25_a).

Individual-level scatterplots (Fig. 25_b) revealed that most participants exhibited differences in cognitive load across the two MetaLabs, suggesting that the task design and virtual environment were perceived differently between the sessions. However, these differences occurred in varying directions; some participants reported lower cognitive load in the Creativity MetaLab and higher in the Embodiment MetaLab, while others exhibited the opposite pattern. Interestingly, a significant number of participants clustered near the midpoint, indicating relatively balanced cognitive load perceptions across both sessions. The remaining participants predominantly fell into the low-low category, indicating that they experienced low extraneous cognitive load in both MetaLabs, while only few participants reported being in the high-high category, indicating high extraneous cognitive load across both sessions.



a. Distribution
The density plot shows the distribution of extraneous cognitive load scores for the Embodiment (blue) and

b. Individual trends
This scatterplot displays individual extraneous cognitive load scores in the Embodiment MetaLab (x-axis) and

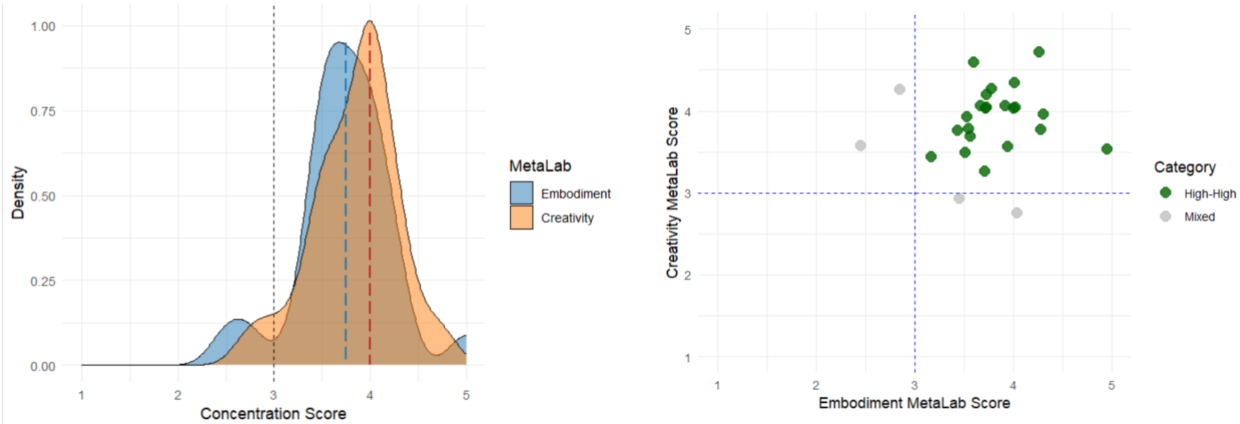
Creativity (orange) MetaLabs. The dashed vertical black line at a score of 3 represents the theoretical midpoint of the scale. The blue and red dashed lines correspond to the median values of extraneous cognitive load scores for the MetaLabs.

Creativity MetaLab (y-axis), categorized into three groups: high social presence (high-high, green) low extranous cognitive load in both MetaLabs (low-low, red) or different experiences in the two MetaLabs (mixed, gray).

Fig. 25. Extraneous cognitive load scores

Concentration levels were consistent across the two MetaLabs. The mean scores were moderately high for both the Embodiment MetaLab (M = 3.23, SD = 0.64) and the Creativity MetaLab (M = 3.12, SD = 0.60), indicating that participants were able to remain focused on the tasks. Overlap analysis (η = 0.88) supported the observation of similar concentration levels between the two (Fig. 26_a).

Individual-level scatterplots (Fig. 26_b) revealed that most participants concentrated well during the bot the Embodiment and Creativity MetaLab, with only a few participants displaying variability in concentration.



a. *Distribution*
The density plot shows the distribution of concentration scores for the Embodiment (blue) and Creativity (orange) MetaLabs. The dashed vertical black line at a score of 3 represents the theoretical midpoint of the scale. The blue and red dashed lines correspond to the median values of concentration scores for the MetaLabs.

b. *Individual trends*
This scatterplot displays individual social presence scores in the Embodiment MetaLab (x-axis) and Creativity MetaLab (y-axis), categorized into three groups: high concentration in both MetaLabs (high-high, green) low concentration in both MetaLabs (low-low, red) or different experiences in the two MetaLabs (mixed, gray).

Fig. 26. Concentration scores

3.1.4.3 Affective dimension

Participants' emotional experiences were analyzed for seven epistemic emotions (Tab. 13).

Tab. 13. Descriptive statistics about epistemic emotions

		Percentiles				
	Mean (sd)	*25*	*50*	*75*	*sk*	*kur*
Surprise						
Embodiment MetaLab	3.52 (0.60)	3.00	3.67	4.00	-0.47	2.15
Creativity MetaLab	3.61 (0.75)	3.00	3.33	4.00	0.30	2.35
Curiosity						
Embodiment MetaLab	4.24 (0.42)	4.00	4.00	4.50	0.05	2.43
Creativity MetaLab	3.98 (0.60)	3.50	4.00	4.50	-0.06	2.37
Enjoyment						
Embodiment MetaLab	3.83 (0.54)	3.00	3.33	3.67	-0.03	2.91
Creativity MetaLab	3.14 (0.72)	3.00	3.00	3.33	0.79	4.54
Confusion						
Embodiment MetaLab	2.02 (0.63)	1.67	2.00	2.33	0.23	2.44

Creativity MetaLab	2.42 (0.79)	1.83	2.67	3.00	0.05	2.61
Anxiety						
Embodiment MetaLab	1.35 (0.51)	1.00	1.00	1.50	1.72	5.68
Creativity MetaLab	1.47 (0.59)	1.00	1.33	1.83	1.38	4.75
Frustration						
Embodiment MetaLab	1.37 (0.53)	1.00	1.00	1.67	1.64	5.15
Creativity MetaLab	1.63 (0.67)	1.00	1.33	2.00	1.02	3.15
Boredom						
Embodiment MetaLab	1.35 (0.48)	1.00	1.00	2.50	1.38	3.88
Creativity MetaLab	1.56 (0.47)	1.00	1.56	2.00	0.36	2.34

The emotional experiences of participants revealed a predominance of positive emotions across both MetaLabs. Curiosity (Embodiment MetaLab: M = 4.24, SD = 0.42; Creativity MetaLab: M = 3.98, SD = 0,60), enjoyment (Embodiment MetaLab: M = 3.83, SD = 0,54; Creativity MetaLab: M = 3.14, SD = 0,72), and surprise (Embodiment MetaLab: M = 3.52, SD = 0,60; Creativity MetaLab: M = 3.61, SD = 0,75) were the most frequently reported emotions, reflecting the positive experience activated. These emotions were particularly pronounced in the Embodiment MetaLab. In contrast, negative emotions such as confusion (M < 2.5 for both MetaLabs), anxiety (M < 2.5 for both MetaLabs), frustration (M < 2.5 for both MetaLabs), and boredom (M < 2.5 for both MetaLabs) were reported at low levels. The radar chart (Fig. 27) highlighted the emotional profiles for both sessions, showing positive emotions dominated participants' experiences, while negative emotions were minimal.

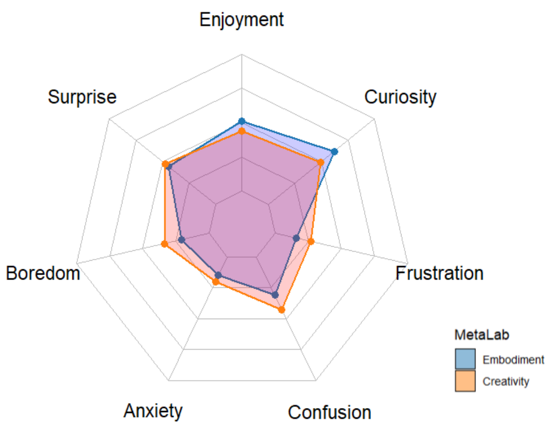


Fig. 27. Radar chart for epistemic emotions

3.1.5 Discussion

The present study examined two MetaLabs integrated within a university course entitled *"VR Techniques and Metaverse for Wellbeing,"* which focused on exploring the applications of XR technologies to promote mental and emotional well-being. Following the instructional design approach described in chapter 2, the two MetaLabs were collaboratively co-designed with the instructor, resulting in two immersive experiences conducted on a social VR platform. Although the two MetaLabs had differing content and learning objectives, they were intentionally designed to elicit similar types of learning experiences. This deliberate alignment provided a unique opportunity to examine both the consistency of students' responses and the individual variability in how they engaged with each MetaLab. Notably, this study represents one of the first investigations of XR labs embedded in a university course, alongside similar pioneering efforts at Stanford University (Han et al., 2022). The findings provide valuable insights into how students perceive and engage with XR-based learning environments, addressing the study's objectives of evaluating the overall quality of the experiences, comparing the two MetaLabs, and identifying individual trends in social, cognitive, and emotional dimensions.

The first objective (O1) focused on analysing students' overall experience within the MetaLabs, with specific attention to how the XR learning environments supported social presence, cognitive engagement, and emotional involvement. The second objective (O2) concerned the identification of individual variations in these experiences, exploring how students interacted with and responded to the MetaLabs across social, cognitive, and affective domains. The following sections discuss each of these dimensions in detail, outlining both group-level trends and individual differences.

Regarding *social presence,* results indicated consistently moderate-to-high levels across both MetaLabs, with mean scores exceeding the theoretical midpoint (3) on the 5-point Likert scale. These results suggest that participants generally experienced a sense of connection and engagement within the immersive environment. Overlap analysis revealed a strong similarity in the distribution of social presence scores between the two sessions, indicating that the MetaLab design effectively fostered comparable levels of connection and co-presence regardless of the thematic focus (i.e., embodiment vs. creativity). The consistently high social presence observed underscores the potential of virtual reality social (VRS) platforms to replicate interpersonal connection and immediacy typically found in face-to-face learning contexts. This is particularly relevant given the well-documented role of social presence in promoting participation, collaboration, engagement, and learning gains in online and blended learning environments (Weidlich & Bastiaens, 2017; Richardson et al., 2017).

It should be noted, however, that participants engaged with the MetaLab activities while sharing the same physical space. Comparing co-located and remote implementations would provide greater clarity on whether the pedagogical affordances of the MetaLab model generalize beyond shared physical settings, a question with implications for instructional design, platform requirements, and institutional adoption strategies. At an individual level, most participants reported stable social presence across both sessions, with the majority scoring high in both. Nonetheless, three participants consistently reported low social presence in both MetaLabs, and two exhibited fluctuations between sessions. This variability suggests the importance of examining individual factors influencing the experience of social presence in immersive environments, such as computer anxiety and prior experience with IVR technologies (Han et al., 2024). Understanding such factors will be essential for designing inclusive and adaptive IVR learning experiences.

In relation to the *cognitive dimension*, the analysis focused on extraneous cognitive load and concentration. Both MetaLabs were designed to minimize extraneous cognitive load and enhance concentration by featuring minimalist virtual environments with low visual complexity and segmenting tasks into manageable phases. This design strategy aimed to reduce unnecessary distractions and direct attention toward the core learning objectives, thereby promoting sustained cognitive engagement. Findings indicated low-to-moderate levels of extraneous cognitive load across both sessions, with all mean scores below the theoretical threshold of 3, suggesting that the environments were perceived as manageable. Concentration levels were similarly consistent, with most participants reporting moderate-to-high focus. These results reflect the effectiveness of the minimalist design and structured task sequencing (i.e., individual, paired, and group tasks) in maintaining attention and reducing mental strain. Such outcomes align with previous findings demonstrating that well-designed virtual environments enhance learner engagement when cognitive load is effectively managed (Makransky et al., 2019; Parong & Mayer, 2018). Minimalist environments characterized by low perceptual complexity help learners focus on relevant content (Skulmowski & Xu, 2022), while task segmentation, a well-established principle of multimedia learning (Mayer & Moreno, 2003), supports concentration by dividing complex tasks into smaller, achievable units (Kirschner, Ayres, & Chandler, 2011). These findings confirm that immersive IVR environments do not necessarily overwhelm learners (Poupard et al., 2025) when designed in accordance with cognitive design principles.

Nevertheless, individual-level variability in extraneous cognitive load indicates that adaptive strategies may be required to meet diverse learner needs. Although most participants experienced manageable cognitive demands, some exhibited higher load levels, suggesting a need for additional support mechanisms. In this respect, the pre-training principle from multimedia learning theory is particularly pertinent (Han et al., 2024; Miguel-Alonso et al., 2023; Miguel-Alonso et al., 2024). Pre-training familiarizes learners with tools and interfaces prior to the learning activity, reducing the novelty effect and allowing greater focus on instructional content. Empirical evidence supports the effectiveness of pre-training in improving learning experience and performance in immersive environments (Han et al., 2024; Meyer, Omdahl & Makransky, 2019), highlighting the importance of introductory technology-briefing sessions to ensure students can effectively use IVR tools (Keskitalo & Saukkorijpi, 2025).

Regarding the *emotional dimension*, results revealed that positive emotions predominated throughout both MetaLabs, with curiosity, enjoyment, and surprise being the most frequently reported. Negative emotions such as confusion, anxiety, frustration, and boredom were comparatively rare, indicating that the experiences were engaging and not overwhelming. These findings align with prior studies showing that IVR environments that promote active exploration tend to evoke curiosity, joy, and surprise (Allcoat & von Muhlenen, 2018; Dubovi, 2022; Cheng, 2023; Guerra-Tamez, 2023; Sun Joo & Lin, 2024).

Nevertheless, the potential influence of the *novelty effect* must be considered, as positive reactions may partially stem from the excitement of using an unfamiliar technology rather than from the learning content itself (Miguel-Alonso et al., 2024). Research indicates that initial exposure to IVR often elicits heightened engagement and enjoyment that may diminish over time (Miguel-Alonso et al., 2023), thus necessitating longitudinal investigations to determine the persistence of positive emotional responses beyond initial use.

3.1.5.1 Limitations and Future Research

Although this study yielded some useful insights, several limitations should be acknowledged. First, the analysis represents an initial snapshot of participants' experiences and does not assess the long-term educational impact of XR integration. Future research should examine the sustained use of XR technologies across curricula to evaluate scalability and pedagogical effectiveness. Additionally, the role of instructors remains underexplored, despite being central to the success of XR implementations. Future investigations should incorporate teacher perspectives, skills, and training requirements. The study also focused on learning experiences rather than knowledge retention or skill transfer, which remain critical areas for future examination (Goh et al., 2017; Schrader et al., 2024).

Second, potential self-selection bias may have influenced the results, as participants were enrolled in a course specifically focused on IVR technologies and thus may have exhibited higher motivation and interest than the general student population. To enhance generalizability, future studies should involve participants from diverse academic backgrounds and varying levels of XR familiarity.

Third, the sample size was limited, which constrained the exploration of individual differences such as computer anxiety (Han et al., 2024) that may moderate learning outcomes. Expanding the participant pool would enable more nuanced analyses of these variables, consistent with the MetaLab framework's emphasis on inclusivity and adaptability. The small sample also precluded the examination of potential interrelations among psychological dimensions. Previous studies have identified connections between social presence and cognitive engagement (Dunmoye et al., 2024), social presence and emotional experience (Pfaller et al., 2021), and cognitive engagement and emotion (Dubovi, 2022; Schrader et al., 2024), suggesting the need for multivariate analyses in future research.

Overall, the findings offer substantial support for the MetaLab framework, emphasizing its pedagogically driven, learner-centered orientation. In contrast to technology-centric initiatives that prioritize hardware and novelty, MetaLabs foreground instructional goals, engagement, and inclusivity. By embedding immersive and experiential learning principles within higher education curricula, MetaLabs serve as transformative environments that facilitate meaningful learning experiences.

In conclusion, the evaluation conducted immediately after the immersive sessions highlighted the effectiveness of XR-based educational designs in fostering positive learning outcomes across the three key psychological dimensions. Social presence was consistently high, demonstrating the capacity of VRS platforms to replicate interpersonal connection and collaboration typical of in-person learning. Cognitive engagement was reflected in low extraneous cognitive load and high concentration, suggesting that minimalist design and structured task segmentation effectively supported focus. Emotional experiences were predominantly positive, characterized by curiosity, enjoyment, and surprise, indicating that the immersive and interactive nature of the MetaLabs successfully promoted active and meaningful learner engagement.

3.1.6 Conclusions

This study examined how immersive virtual environments influence key psychological dimensions of learning within structured XR-based educational experiences developed through the MetaLab framework. Specifically, it explored the impact of these experiences on students' social presence, cognitive engagement, and emotional involvement within a university course titled *VR Techniques and Metaverse for Well-being.*

Findings indicate that the MetaLabs effectively supported all three psychological dimensions. Students reported moderate-to-high levels of co-presence and interpersonal connection, demonstrating the capacity of well-designed immersive environments to foster social presence comparable to in-person learning. Cognitive engagement was characterized by low extraneous cognitive load and sustained concentration, facilitated by the structured design that progressively moved from individual to collaborative activities. Emotional involvement was largely positive, with curiosity and enjoyment emerging as dominant affective states, suggesting that XR-based learning experiences can promote active and intrinsically motivated participation. Minimal reports of frustration and confusion further confirm that pedagogically grounded XR environments can optimize learning engagement while preventing cognitive overload.

Nevertheless, several limitations must be acknowledged. The relatively small sample size constrains the generalizability of the findings, and the short-term design does not allow conclusions about long-term learning outcomes such as retention or transfer. Moreover, participant self-selection may have introduced bias, as students enrolled in the course might have possessed a pre-existing interest in immersive technologies, potentially influencing their engagement and attitudes.

Future research should extend the investigation to diverse academic disciplines and longitudinal contexts to assess the enduring impact of XR-based learning on knowledge consolidation, skill acquisition, and motivation. Broader samples and mixed-method approaches would allow a more comprehensive understanding of how individual differences, teaching styles, and disciplinary contexts interact with the MetaLab framework. As XR technologies continue to evolve, the MetaLab approach offers a scalable, pedagogically grounded model capable of integrating innovation with educational rigor.

Building upon these findings, the next study of the *Test and Evaluation* phase (i.e., "Usability, Effort, and Continuance Intention in Sixteen MetaLabs") will broaden the analytical scope to include a larger set of immersive experiences co-designed with university faculty who participated in the *Empathize* phase of the research project. This subsequent investigation will encompass sixteen MetaLabs developed across different disciplines, focusing on how usability, perceived effort, and continuance intention vary according to instructional context and design.

3.2 Test and Evaluation Study 2: Usability, Effort, and Continuance Intention in Sixteen MetaLabs

As part of the *Test and Evaluation* phase, this study extends the investigation of immersive learning by examining the dimensions of usability, effort, and continuance intention across sixteen MetaLabs implemented within authentic higher education settings. As previously described, these MetaLabs were co-designed with university faculty who participated in the *Empathize* phase of the research project and developed according to the MetaLab framework (*see* Chapter 2). Each MetaLab was integrated into existing university courses and implemented through immersive or semi-immersive XR technologies, enabling the systematic observation of user experience across diverse instructional contexts.

This study builds upon the preliminary investigation conducted on two MetaLabs, which explored students' social, cognitive, and emotional experiences in immersive learning environments. By expanding the analysis to a larger number of MetaLabs, the present work aims to examine how variations in pedagogical design and technological configuration influence perceived usability, cognitive effort, and the intention to continue using XR tools for learning. This approach contributes to refining the MetaLab framework and to assessing its scalability and effectiveness across disciplines. The outcomes of this research were presented at the CKBG Symposium in Florence in November 2025[12].

3.2.1 Rationale and Objectives

The effectiveness of XR-based education is closely linked to the quality of the *user experience (UX),* understood as the overall set of users' perceptions, emotions, and cognitive responses that arise during interaction with a system (ISO 9241-210, 2019). In immersive learning, UX represents a multidimensional construct encompassing usability, comfort, presence, engagement, and cognitive load (Makransky & Petersen, 2021; Parong & Mayer, 2018). Because XR learning environments rely on sensory immersion, embodied interaction, and spatial navigation, their UX depends not only on technological performance but also on how effectively the interface supports intuitive and cognitively efficient interaction (Dede, 2009; Johnson-Glenberg, 2018). Positive UX in educational XR contexts has been shown to enhance focus, motivation, and conceptual understanding, whereas negative UX, characterized by disorientation, fatigue, or frustration, can disrupt learning processes and diminish perceived value (Makransky & Lilleholt, 2018; Rupp et al., 2019).

Within the broader UX construct, *perceived usability* constitutes a key determinant of both learning effectiveness and technology acceptance. According to the ISO 9241-11 standard (2018), usability refers to the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use. In XR learning environments, perceived usability reflects the degree to which learners find the system intuitive, navigable, and conducive to completing educational tasks without excessive effort or confusion (Makransky & Petersen, 2019; Rupp et al., 2019). High usability minimizes *extraneous cognitive load*, the mental effort caused by non-essential interface complexity (Sweller, 2010; Mayer, 2005), thereby allowing students to direct cognitive resources toward meaningful learning activities. Conversely, poor usability can contribute to cognitive overload and physical strain, particularly when interactions require extensive motor coordination or prolonged headset use (Rebenitsch & Owen, 2016; Stanney et al., 2020).

From a theoretical standpoint, perceived usability can be situated within established models of technology adoption (i.e., Technology Acceptance Model and the Extended Expectation-Confirmation Model). In these frameworks, usability corresponds closely to the construct of *perceived ease of use*, a central

[12] Bartolotta, S., Di Natale, A. F., Ubaldi, A., Villani, D., & Gaggioli, A. (2025, November). *Apprendere in ambienti immersivi: Il ruolo chiave dell'esperienza utente nei MetaLab universitari* [Paper presentation]. CKBG Symposium, Florence, Italy.

antecedent of user satisfaction and *continuance intention*, the willingness to continue using a technology after initial exposure. In XR learning, this relationship has been empirically supported: learners who perceive immersive systems as easy to use and cognitively manageable are more likely to experience enjoyment, self-efficacy, and motivation for future engagement (Makransky & Petersen, 2021; Han et al., 2024).

Despite these insights, empirical evidence on the role of usability in predicting continued XR use and its relationship to cognitive and physical effort remains limited, particularly in authentic higher education contexts. Much of the existing research is based on controlled laboratory experiments that, while methodologically rigorous, lack ecological validity and do not fully capture the complexity of real-world curricular implementation (Jensen & Konradsen, 2018; Radianti et al., 2020). Consequently, there is a need for field-based investigations that examine how usability influences both immediate learning experience and longer-term adoption within diverse academic disciplines.

The present study seeks to address this gap by investigating usability as a strategic leverage point for sustainable XR adoption in higher education, with three main aims:

(i) To examine the association between perceived usability, measured through the *System Usability Scale* (SUS; Brooke, 1996), and students' intention to continue using XR tools in their future learning activities.

(ii) To explore the relationship between perceived usability and perceived effort, focusing on cognitive, physical, and overall effort experienced after XR learning sessions.

(iii) To provide baseline descriptive data on usability and effort across a large and heterogeneous sample of 142 students from multiple degree programs and XR implementations, thereby offering empirical benchmarks for future research and design evaluation.

The study also seeks to generate evidence-based recommendations for instructional designers and faculty by illustrating how enhancing usability can simultaneously reduce students' cognitive and physical burden and strengthen motivation for continued XR engagement. More broadly, it promotes a user-centered, interdisciplinary approach to XR-based pedagogy that integrates teachers, immersive learning designers (ILeaDs), and developers to ensure that technological innovation remains aligned with pedagogical goals.

This research is situated within the broader *Metaversity* project, which implemented MetaLab learning activities across multiple university courses through collaborative co-design with faculty members (Gaggioli et al., 2024). This university-wide, interdisciplinary deployment provides a diverse dataset for examining user experience factors that shape both learner engagement and the sustainable adoption of XR technologies.

By analyzing these relationships, the study aims at contributing to a more comprehensive understanding of how perceived usability mediates the interplay between immersive design, cognitive load, and technology acceptance, positioning user experience not as a peripheral technical consideration, but as a core pedagogical determinant influencing both the effectiveness and long-term integration of XR-based learning in higher education.

3.2.2 Theoretical Background

The success of XR technologies in the learning process depends not only on their technical affordances alone but on the quality of the *user experience (UX)* they provide. Within the field of cognitive and affective psychology, UX has been conceptualized as a holistic and subjective phenomenon that integrates perceptual, cognitive, and emotional processes arising during the interaction between a user and a system (Hassenzahl & Tractinsky, 2006; Mahlke, 2008). According to the International Organization for Standardization (ISO 9241-210, 2019), UX is defined as a person's perceptions and responses resulting from the use or anticipated use of a product, system, or service. This definition emphasizes that UX extends beyond instrumental aspects such as efficiency or accuracy to include affective and experiential qualities, such as enjoyment, engagement, and trust (Norman, 2004; Hassenzahl, 2010). In psychological terms, UX can be viewed as a dynamic interplay between cognitive appraisal (e.g., perceived ease, control, or mental effort), affective reaction (e.g., curiosity, enjoyment, frustration), and motivational outcomes (e.g., intention to use, persistence, or disengagement).

In immersive learning contexts, these processes become particularly salient due to the multisensory, interactive, and embodied nature of XR systems. Makransky and Petersen (2021) propose that positive UX in immersive learning is characterized by a state of cognitive manageability, affective involvement, and presence, conditions that support meaningful engagement and deeper learning. Similarly, Parong and Mayer (2018) and Makransky, Terkildsen, and Mayer (2019) show that when immersive systems align perceptual richness with cognitive clarity, learners experience higher motivation and comprehension. Conversely, negative UX arises when sensory or cognitive demands exceed users' processing capacity, leading to disorientation, fatigue, or cognitive overload, conditions that have been shown to impair both performance and retention (Makransky & Mayer, 2022; Skulmowski & Rey, 2018).

Psychological models of UX (e.g., Hassenzahl, 2010; Mahlke & Thüring, 2007) conceptualize the experience as a multidimensional construct with at least three major components: (i) instrumental qualities (e.g., usability, controllability, efficiency), which influence task performance and perceived ease of use; (ii) non-instrumental qualities (e.g., aesthetics, stimulation, identification), which shape emotional responses and personal meaning; and (iii) emotional consequences, such as satisfaction or frustration, that drive longer-term attitudes and behavioral intentions. In XR learning environments, these dimensions are not independent: high usability and clear affordances foster positive affective states like enjoyment and curiosity, which in turn reinforce intrinsic motivation and learning persistence (Bacca et al., 2014; Makransky & Lilleholt, 2018).

Furthermore, research in affective computing and motivational psychology suggests that positive UX enhances learners' self-efficacy and autonomy, two factors closely linked to sustained engagement and continuance intention (Deci & Ryan, 2000; Bandura, 1997). When learners perceive immersive technologies as usable, supportive, and cognitively manageable, they are more likely to experience flow-like states, characterized by deep absorption, reduced self-consciousness, and intrinsic enjoyment (Csikszentmihalyi & Csikszentmihalyi, 1990; Johnson-Glenberg, 2018). Conversely, frustration, confusion, or discomfort can elicit negative affective states that undermine concentration and motivation, highlighting the bidirectional relationship between UX quality and learning performance (Mahlke, 2008; Pekrun, 2006).

Within the UX field, an important key factor to consider in *perceived usability*, which captures how intuitive, navigable, and cognitively manageable the system feels to students (Makransky et al., 2019; Rupp et al., 2019). High usability reduces *extraneous cognitive load*, the mental effort produced by nonessential interface complexity (Sweller, 2010; Mayer, 2005), allowing learners to direct cognitive resources toward meaningful learning tasks. Conversely, poor usability increases both cognitive and physical strain, particularly in systems requiring extensive motion control or prolonged headset use (Rebenitsch & Owen, 2016; Stanney et al., 2020). The System Usability Scale (SUS) (Brooke, 1996) remains a standard tool for evaluating this construct, with benchmark studies (Bangor, Kortum, & Miller, 2009) showing that scores above 70 generally indicate acceptable usability.

A second key factor in the adoption of XR technologies is *intention to use*, conceptualized in technology acceptance research as a critical predictor of both initial adoption and long-term integration. The Technology Acceptance Model (TAM) (Davis, 1989) posits that two core beliefs, perceived usefulness and perceived ease of use, determine users' attitudes toward technology and their behavioral intentions. The Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) expand this model by including performance expectancy**,** effort expectancy**,** social influence, and facilitating conditions, while the Expectation-Confirmation Model (ECM) and its educational extension (EECM; Bhattacherjee, 2001; Lee, 2010) describe how satisfaction and confirmation of expectations shape continuance intention. Applied to XR, these frameworks show that both *usefulness* and *usability* (effort expectancy) strongly influence students' motivation and willingness to continue using immersive tools (Sagnier et al., 2020; Di Natale et al., 2024b). Sagnier et al. (2020) reported that perceived usefulness significantly predicts intention to use VR, whereas negative experiences such as *cybersickness* reduce it. Similarly, Di Natale et al. (2024b) demonstrated that effort expectancy, a conceptually close to perceived usability, was a significant predictor of behavioral intention, confirming that ease of interaction remains a crucial determinant of acceptance in immersive contexts.

Cybersickness refers to a constellation of discomfort symptoms that may occur during or after exposure to immersive virtual environments, including nausea, dizziness, eyestrain, disorientation, and headaches. It is commonly conceptualized as a form of visually induced motion sickness and represents one of the most frequently reported adverse effects associated with immersive XR technologies (LaViola, 2000; Rebenitsch & Owen, 2016). From a theoretical perspective, cybersickness is primarily explained by the *sensory conflict theory*, according to which symptoms emerge from a mismatch between visual cues indicating self-motion and vestibular or proprioceptive signals signaling bodily stability (Reason & Brand, 1975; Oman, 1990). Additional contributing factors include system-related variables, such as latency, low or unstable frame rates, and tracking inaccuracies, as well as interaction-related features, including artificial locomotion, visual acceleration, and incongruence between user actions and system feedback (LaViola, 2000; Stanney et al., 2020).

In educational XR contexts, cybersickness constitutes a particularly relevant challenge, as it can negatively affect attention, motivation, task performance, and ultimately learning outcomes (Rebenitsch & Owen, 2016). This issue becomes especially salient in learning activities that rely on active interaction, navigation, or prolonged immersion, which are often essential for experiential and embodied learning approaches. Consequently, reducing cybersickness should be regarded not merely as a matter of user comfort, but as a prerequisite for pedagogical effectiveness. Empirical research suggests several design and instructional strategies to mitigate cybersickness in learning-oriented XR environments, including minimizing artificial locomotion in favor of teleportation or physical movement, maintaining high and stable frame rates, reducing visual acceleration, and ensuring tight coupling between physical actions and virtual feedback (Stanney et al., 2020; Weech et al., 2019). Furthermore, gradual onboarding procedures, short and progressive exposure sessions, and opportunities for learners to self-regulate interaction pace have been shown to reduce symptom severity and improve tolerance over time (Rebenitsch & Owen, 2016).

Importantly, pedagogical design choices play a central role in managing cybersickness. Learning activities that emphasize meaningful, task-oriented interaction and clear action–feedback contingencies can reduce perceptual conflict and cognitive overload, thereby attenuating discomfort (Makransky & Petersen, 2019). From this perspective, addressing cybersickness as a design constraint rather than a marginal side effect enables the sustainable and responsible integration of XR technologies into real-world educational settings, particularly those that depend on active and embodied forms of learning.

A third factor of growing interest in immersive education research is *perceived cognitive load*, which describes the mental resources required to process and integrate information during learning. Cognitive Load Theory (CLT) (Sweller, 2010) distinguishes between intrinsic load (task-related difficulty), extraneous load (caused by suboptimal design), and germane load (resources devoted to schema construction and learning). XR environments, by their nature, can both enhance and hinder learning depending on how they manage these forms of cognitive demand. Poorly designed virtual interfaces may amplify extraneous load, diverting attention from learning objectives, while well-structured immersive tasks can optimize germane load, promoting deeper understanding and engagement (Makransky et al., 2019). Research by Poupard et al. (2025) indicates that novices are particularly susceptible to overload due to environmental complexity and novelty effects, whereas more experienced users benefit from XR training, an effect consistent with the expertise reversal effect (Kalyuga, 2009). Skulmowski and Xu (2022) proposed a cost–benefit model of cognitive load, suggesting that a moderate increase in cognitive demand, when aligned with pedagogical objectives, can enhance learning and motivation. Similarly, Gonnermann-Müller and Teichmann (2023) found that prior experience reduces perceived effort and improves learning outcomes, while immersion level alone did not predict performance, reinforcing the importance of usability and familiarity in shaping cognitive load.

Collectively, these theoretical and empirical insights indicate that perceived usability**,** intention to use**,** and perceived cognitive load are deeply interrelated in determining both the effectiveness and sustainability of XR learning. Usability influences how intuitive learners interact with XR systems; cognitive load reflects the mental effort such interactions require; and intention to use represents the motivational outcome that predicts future engagement and long-term adoption (Makransky & Petersen, 2021; Han et al., 2024). Investigating the interplay among these constructs is therefore essential to understand how immersive technologies can be integrated into higher education in pedagogically meaningful and sustainable ways.

This study aims to explore in greater depth the relationships among three key factors: (i) perceived usability, (ii) intention to use, and (iii) perceived cognitive load, that may influence university students' acceptance of XR technologies in hybrid learning environments. The study is part of the broader Metaversity project, and integrated 16 MetaLab within university courses across Milan, Piacenza, Brescia, and Cremona. The study aims to contribute to the growing body of empirical research on XR adoption by providing ecologically valid evidence from authentic university settings and by demonstrating that improving usability may simultaneously reduce students' cognitive burden and enhance their motivation for sustained engagement with XR learning environments.

3.2.3 Methods

The study adopted a quantitative research design based on a structured self-report questionnaire administered at the conclusion of each MetaLab session. This study employed the evaluation protocol described in Section 2.5, which was developed to systematically assess students' subjective experiences in immersive learning contexts. Although the broader research design originally included two measurement points (pre- and post-experience), the present study focuses exclusively on the post-experience phase. During this stage, participants completed a battery of standardized questionnaires aimed at evaluating three core dimensions of the immersive learning experience: (i) perceived usability, reflecting the ease and intuitiveness of interaction with the XR system; (ii) intention to use, indicating learners' willingness to continue engaging with immersive technologies in future educational contexts; and (iii) perceived effort, encompassing both cognitive and physical components related to task performance and system interaction.

Data collection was conducted anonymously and on a voluntary basis through the Qualtrics online platform. Participants were invited to complete the questionnaires immediately after the MetaLab activity to ensure accuracy of recall and to capture their direct impressions of the immersive learning experience. This timing was chosen to minimize retrospective bias and to preserve the ecological validity of participants' affective and cognitive responses.

All procedures complied with ethical research standards. The study protocol was reviewed and approved by the Ethics Committee for Research in Psychology (C.E.R.P.S.) at the Università Cattolica del Sacro Cuore, Milan, and conducted in accordance with the principles of the Declaration of Helsinki and institutional guidelines governing research involving human participants.

3.2.3.1 Participants

The sample for the present analysis comprised 142 university students ($M_{età} = 23.3$, $DS_{età} = 4.97$; 61 F, 12 M) who took part in the MetaLabs delivered during the 2024/2025 a.y. and completed the post-experience questionnaire.

The sample included students enrolled in undergraduate, graduate and postgraduate programs across different courses (*see* Procedure paragraph for details). Although individual demographic variables were not collected in the questionnaire, the heterogeneous composition of the subsample reflects the disciplinary breadth and multidimensional character of the project.

3.2.3.2 Measures

- *Perceived usability* of the tools used in the MetaLab was assessed with the System Usability Scale (SUS) (Brooke, 1996), a 10-item measure rated on a 5-point Likert scale (1 = *strongly disagree* to 5 = *strongly agree*). The scale is widely validated for assessing user-interface quality in digital contexts and was adapted to the immersive educational context (both VR and desktop) with a brief clarifying introduction.
- Students' *intention to use* XR technologies for learning purposes was measured with a 3-item subscale (items 13–15) derived and adapted from the post-EECM questionnaire (Di Natale et al., 2024b). Participants indicated their level of agreement with the following statements: "I intend to use MetaLabs for learning in the future"; "I will continue to attend MetaLabs for learning as much as possible in the future"; "I will continue to follow MetaLabs for learning in the future." Responses were recorded on a 5-point Likert scale (1 = *strongly disagree* to 5 = *strongly agree*).
- *Perceived cognitive and physical effort* was measured using a bespoke 3-item section inspired by Paas and Van Merriënboer (1993). Participants self-reported the mental effort, the physical effort, and the total amount of mental and physical energy required to complete the activity. Responses were collected on a 5-point Likert scale (1 = *not at all* to 5 = *very much*), designed to facilitate an immediate and intuitive response at the end of the immersive experience.

3.2.3.3 Procedure

Data was collected at the end of each MetaLab session. The MetaLabs, implemented across multiple university courses and campuses, were designed as interdisciplinary learning modules integrating immersive and desktop-based XR experiences. Each MetaLab incorporated different instructional activities, such as interactions in metaverse environments, asynchronous avatar-based group work, and experiential simulations, using a variety of XR technologies, including immersive virtual reality (IVR) and non-immersive solutions (desktop, tablets and mobile devices) (Tab. 14).

Platforms and applications like Spatial, Labster, Matterport, Wander, and VirtualSpeech were selected according to course objectives to support the visualization of abstract concepts, the simulation of real-world scenarios, and the promotion of experiential and collaborative learning.

Tab. 14. Summary informations of the MetaLabs

Course	**Campus**	**MetaLab Concept**

Sociology of Digital Media	Milan	Visualization of concepts related to the VR medium and virtuality-reality continuum on *Spatial* app with *IVR*.
English for Psychology	Brescia	Use of *IVR* and the *VirtualSpeech* app for public speaking simulations in English.
General Psychology	Piacenza	Use of *Spatial* app and *IVR* to perform a series of interactive minigames about general psychology constructs (e.g., memory, attention, motivation).
Analytical Chemistry	Piacenza	Desktop-based simulation of chemistry laboratory experiments using *Labster app.*
Analytical Chemistry	Cremona	Desktop-based simulation of chemistry laboratory experiments using *Labster app.*
History of Contemporary Architecture	Milan	Use of *Matterport* technology to explore Casa Batlló in a virtual environment.
Methods and Techniques of Human Resource Management	Milan	Use of the *BecomeVR* app for a corporate well-being training experience.
Institutions of Political Economy	Brescia	Immersive simulation in *Spatial* with *IVR* of the Tragedy of the Commons to explain concepts related to economics and sustainability.
Master in Sustainable Business Administration (pt.1)	Milan	Use of *IVR* and the *Eye in the Storm* app to explore themes of natural disasters and sustainability.
Master in Sustainable Business Administration (pt. 2)	Milan	*Desktop-based* simulation on *Spatial* app of a United Nations session addressing sustainability issues.
Psychology of New Technologies: Risks and Opportunities for Self and Relationships	Brescia	Visualization of concepts related to the VR medium and virtuality-reality continuum on *Spatial* app with *IVR* to discuss about risks and potentials of XR technologies.
Institutions of Film History	Milan	Visualization of the main milestones in the history of cinema in the *Spatial* app via *desktop* and observation of the immersive short film *The Line* via *IVR* to discuss new cinematic styles.
Well-being, Empowerment and Positive Technologies	Milan	Visualization of concepts related to the VR medium and virtuality-reality continuum on *Spatial* app with *IVR* to discuss about XR well-being solutions.

General Psychology Laboratory	Milan	Use of *IVR* and the *VirtualSpeech* app for practicing empathic communication skills.
Geography (with Laboratory)	Milan	Use of the *Wander* app via IVR to explore key locations from a virtual walk through Milan's Chinatown, focusing on urban transformation.
Geography (with Laboratory)	online	Exploration of the same urban walk via *Google Street View* via desktop to analyze processes of urban transformation.

The following image presents a selection of virtual environments (both desktop-based and IVR app) illustrating some of the MetaLabs implemented in this study (Fig. 28).

Fig. 28. Sample images of the virtual learning experiences developed in some of the MetaLabs described in Table 13. Specifically, Fig. 28a refers to English for Psychology; Fig. 28b to Sociology of Digital Media; Fig. 28c to General Psychology; Fig. 28d to Methods and Techniques of Human Resource Management; Fig. 28e to History of Contemporary Architecture; Fig. 28f to Institutions of Political Economy; Fig. 28g to Analytical Chemistry; and Fig. 28h to Master in Sustainable Business Administration (Part 2).

3.2.3.4 Data Analysis

Statistical analyses were conducted using Jamovi software (v. 2.7.9) and followed standard procedures to evaluate the reliability of the instruments, describe the variables of interest, and investigate the relationships among usability (SUS), intention to use in the future, and perceived cognitive and physical effort.

First, Cronbach's alpha was computed to assess the internal consistency of the scales employed. Next, descriptive statistics (mean, standard deviation, minimum, and maximum) were calculated for each variable of interest.

To examine the relationships among variables, a simple linear regression analysis was performed with the mean SUS score as the independent variable and the mean score of the intention-to-use items as the dependent variable, to investigate the predictive contribution of perceived usability on the intention to continue using MetaLabs as a teaching approach. Additionally, Spearman's rank-order correlation coefficient was calculated between the SUS score and the mean scores of the future intention-to-use items.

3.2.4 Results

Descriptive analyses indicated that the perceived usability of the technologies employed in the MetaLabs (as measured by the System Usability Scale, SUS) yielded a mean score of 80.51 (SD = 13.51) (Fig. 29), aligning with the thresholds of acceptability reported in the literature (scores above 68 are generally considered satisfactory; Bangor, Kortum, & Miller, 2008).

Fig. 29. Interpretation of SUS benchmark scores (adapted from Bangor, Kortum, & Miller, 2008): scores below 50 are not acceptable, 50–68 is marginal, and above 68 are acceptable.

Regarding perceived effort, findings showed that *cognitive effort* obtained a mean value of 3.05 (SD = 0.96), reflecting a moderate cognitive load during the activities. *Physical effort* recorded a mean value of 2.02 (SD = 1.07), indicating a low level of physical demand, while *overall effort*, integrating both cognitive and physical components, reached a mean value of 2.88 (SD = 0.99), suggesting a medium total workload (Fig. 30).

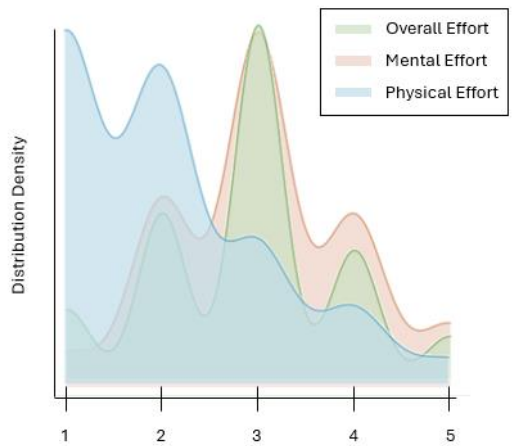


Fig. 30. Distribution of perceived effort across Overall, Mental, and Physical Effort.

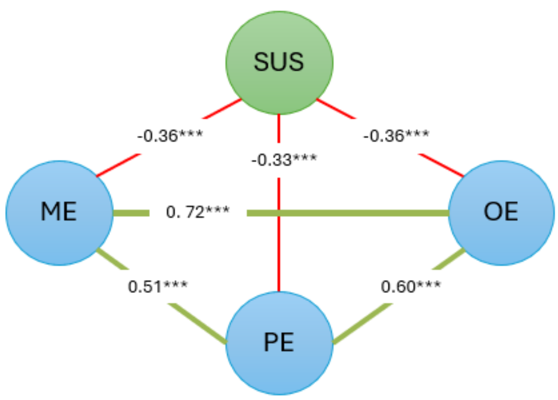
The correlational analyses revealed significant negative associations between perceived usability (SUS) and all measures of perceived effort (cognitive, physical, and overall). Specifically, higher perceived usability was associated with significantly lower cognitive effort ($r = -.36$, $p < .001$), physical effort ($r = -.33$, $p < .001$), and overall effort ($r = -.36$, $p < .001$). These results (Tab. 15) suggest that, as expected, greater usability contributes to reducing both cognitive and physical demands during the use of the XR technologies implemented in the MetaLabs.

Tab. 15. Correlations between usability (SUS) and perceived effort dimensions.

	SUS	MentalEffort	PhysicalEffort	OverallEffort
SUS	—			
MentalEffort	−0.36 ***	—		
PhysicalEffort	−0.33 ***	0.51 ***	—	
OverallEffort	−0.36 ***	0.72 ***	0.60 ***	—

Note. **p < .05, **p< .01, ***p< .001.*

The figure below (Fig. 31) shows the significant correlations among the System Usability Scale (SUS) score and the three dimensions of perceived effort: Mental Effort (ME), Physical Effort (PE), and Overall Effort (OE). Red lines indicate negative correlations, showing that higher usability is associated with lower perceived effort across all dimensions. Green lines represent positive correlations, highlighting strong interrelations among the different types of effort, particularly between mental and overall effort ($r = .72$, $p < .001$). The diagram provides an intuitive overview of how usability inversely relates to cognitive and physical workload in XR learning experiences investigated in this study.



. **Fig. 31.** Graphical representation of correlations between usability and effort dimensions.

Finally, the simple linear regression analysis (Tab. 16) demonstrated that perceived usability was a significant predictor of students' intention to continue using MetaLabs in the future, explaining 16% of the observed variance in this variable ($R^2 = .16$).

Tab. 16. Linear regression predicting continuance intention from perceived usability (SUS).

Predictor	b	SE	t	p
Intercept	1.40	0.38	3.68	< .001
SUS	0.02	0.01	5.19	< .001
	R = 0.40; R² = 0.16			

Note. **p < .05, **p< .01, ***p< .001.*

Overall, these findings confirm the central role of perceived usability as a key factor in mitigating cognitive and physical load during MetaLab activities and in fostering a stronger intention to continue using immersive technologies in future learning practices.

3.2.5 Discussion

The results of this study provide empirical support for the central role of *perceived usability* in shaping students' experiences with immersive and extended reality technologies in higher education. The mean usability score obtained from the System Usability Scale (M = 80.51, SD = 13.51) indicates that the XR technologies used in the MetaLabs were evaluated as highly usable, exceeding the benchmark of 68 generally considered acceptable in the literature (Bangor, Kortum, & Miller, 2009). This outcome suggests that the design and implementation of the MetaLabs successfully supported intuitive interaction and efficient task performance, confirming that XR learning environments can achieve high standards of usability when pedagogical and technical factors are properly aligned.

With respect to *perceived effort*, the data showed a moderate level of cognitive load (M = 3.05, SD = 0.96) and a relatively low level of physical effort (M = 2.02, SD = 1.07), resulting in an overall workload of medium intensity (M = 2.88, SD = 0.99). These findings suggest that while XR learning requires sustained mental engagement, it does not impose excessive physical strain, maintaining a balance between immersion and manageability. In line with Cognitive Load Theory (Sweller, 2010; Mayer, 2019), this pattern indicates that the MetaLab design was effective in minimizing extraneous cognitive load, allowing students to focus their cognitive resources on meaningful learning activities rather than on interface management.

The significant negative correlations between usability and all forms of perceived effort reinforce this interpretation: higher usability was associated with lower cognitive, physical, and overall effort. This relationship aligns with previous studies showing that clear affordances, intuitive navigation, and immediate feedback reduce cognitive burden and enhance engagement in immersive learning (Makransky, Terkildsen, & Mayer, 2019; Parong & Mayer, 2018; Skulmowski & Rey, 2018). Conversely, complex or poorly designed systems have been linked to disorientation, fatigue, and cybersickness (Rebenitsch & Owen, 2016; Stanney et al., 2020), underscoring that usability is a determinant of both cognitive efficiency and learner well-being.

Regression results further demonstrated that perceived usability significantly predicted students' *intention to continue* using XR technologies, explaining 16% of the observed variance. This finding is consistent with the Technology Acceptance Model (TAM) (Davis, 1989), the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003), and the Expectation-Confirmation Model (Bhattacherjee, 2001), which identify *perceived ease of use* (or effort expectancy) as a key antecedent of continuance intention. In the context of XR learning, high usability promotes self-efficacy, autonomy, and intrinsic motivation (Deci & Ryan, 2000; Bandura, 1997), leading to greater engagement and sustainable adoption. These findings echo Sagnier et al. (2020) and Di Natale et al. (2024b), who showed that ease of interaction is among the strongest predictors of students' willingness to adopt immersive technologies.

Overall, these findings confirm that usability functions as both a cognitive and motivational enabler, mediating the relationship between design quality, learning engagement, and adoption intention. Within the framework of the Cognitive-Affective Model of Immersive Learning (CAMIL) (Makransky & Petersen, 2021), usability can be understood as a pivotal construct linking technological affordances to psychological experience, fostering conditions such as manageability, curiosity, and flow (Csikszentmihalyi & Csikszentmihalyi, 1990; Johnson-Glenberg, 2018).

CAMIL conceptualizes learning in immersive media as an indirect process mediated by cognitive and affective variables, such as presence, motivation, emotional engagement, and cognitive load, rather than as a direct consequence of technological immersion (Makransky & Petersen, 2019). This assumption resonates with earlier research in instructional psychology and simulation-based learning, which emphasizes that learning outcomes depend on how learners allocate attention and regulate cognitive resources within rich environments, rather than on realism alone (de Jong, 2010; Clark, 2001). In this respect, CAMIL's key contribution lies in formalizing the non-linear relationship between immersion and learning, highlighting that increasing immersion may generate diminishing returns or even negative effects when it amplifies extraneous cognitive demands.

At the same time, several limitations of CAMIL become particularly salient in applied educational contexts. First, the model primarily adopts an individualistic and post-hoc perspective, relying largely on self-report measures collected after the experience, thus offering limited insight into the temporal dynamics through which immersive learning evolves during prolonged or repeated exposure (Yan et al., 2024). Second, CAMIL underrepresents the role of pedagogical mediation and instructional orchestration, despite evidence showing that guidance, task framing, and scaffolding critically shape learning in immersive and simulation-based environments (Sailer & Homner, 2020). Third, broader contextual and institutional dimensions, such as co-design with educators, curricular constraints, and organizational readiness, remain largely outside the explanatory scope of the model, even though these factors are known to influence the sustainability and effectiveness of educational innovation (Tondeur et al., 2017; Foreman-Brown, Fitzpatrick & Twyford, 2023).

Building on these considerations, the present thesis draws on CAMIL as a foundational explanatory model while extending it through a design-based research perspective that foregrounds ecological validity, iterative refinement, and pedagogical mediation as central mechanisms shaping immersive learning in real-world higher education settings.

From an instructional design perspective, the results highlight the necessity of integrating user experience (UX) evaluation as a core dimension of pedagogical innovation. Ensuring high usability requires interdisciplinary collaboration between educators, instructional designers, and developers, following user-centered principles that balance technological complexity with cognitive accessibility. This approach resonates with the methodologies of Design-Based Research (DBR) and Learning Experience Design (LxD) (Bannan, 2013; Garrett, 2011), which advocates iterative refinement based on real-world data and user feedback to sustain innovation over time.

Although the study provides robust quantitative evidence, it presents some limitations. The cross-sectional design prevents causal inference, and self-report data may not fully capture the depth of students' cognitive and affective experiences. Moreover, the study assessed immediate post-experience perceptions without examining long-term outcomes such as retention or transfer. Future research should adopt longitudinal and mixed-method designs, integrating qualitative interviews, observational analyses, and physiological measures to capture the evolution of UX and usability perceptions across time and contexts. Extending this research across different disciplines and XR modalities will further strengthen the ecological validity and scalability of the MetaLab model.

In practical terms, these findings underscore the importance of a user-centered design approach in the implementation of XR in higher education. Iterative usability testing and stakeholder co-design, methods long established in usability engineering (Nielsen, 1994), should be integrated from early stages of development to identify interface barriers and reduce cognitive friction (Hassenzahl, 2010; Mahlke & Thüring, 2007). Likewise, structured onboarding or pre-training sessions are recommended to mitigate novelty effects and facilitate the acquisition of essential navigation skills, an approach shown to enhance user comfort and confidence in immersive settings (Makransky et al., 2019; Miguel-Alonso et al., 2024; Morgan-Davies et al., 2022).

Educators and instructional designers should also monitor and adapt cognitive load dynamically, introducing complexity gradually in accordance with learners' expertise levels, a strategy consistent with the expertise reversal effect (Kalyuga, 2009) and with the cost–benefit perspective on cognitive load (Skulmowski & Xu, 2022). Institutional strategies should therefore prioritize faculty development and capacity building, providing instructors with training in UX principles, usability heuristics, and inclusive design practices (Settles & Wright, 2018; Radianti et al., 2020). Finally, embedding continuous feedback loops and usability monitoring into XR course design can sustain long-term innovation and prevent disengagement. Adaptive systems that dynamically adjust interface complexity or sensory load based on learner feedback have been shown to improve engagement and reduce effort (Jeon et al., 2023; De Back et al., 2023). By incorporating such practices, educational institutions can move from experimental XR adoption to evidence-based, scalable, and pedagogically grounded immersive learning, in which usability and learner experience are not peripheral technical concerns, but essential drivers of educational quality and sustainability.

3.2.6 Conclusions

The previous study examined the usability and cognitive manageability of XR technologies within the MetaLab framework, showing that perceived usability reduces learners' cognitive and physical effort while enhancing their intention to continue using immersive tools. A positive user experience (UX) emerged as a key precondition for sustainable XR adoption in higher education. However, as outlined in Section 2.1.1, immersive learning extends beyond usability or interface design: learning in XR is an experiential process where cognitive, emotional, and motivational dimensions converge to create meaningful and transformative episodes (Parrish, Wilson, & Dunlap, 2011; Riva et al., 2016; Gaggioli et al., 2019).

Building on this premise, the next study shifts the analytical focus from system usability to the lived experience of learning, examining the emotional, attentional, and motivational dynamics that unfold during XR-based educational activities. This transition aligns with contemporary perspectives in instructional design and learning psychology that view *experience* as the central unit of educational analysis (Parrish, 2009; Laurillard, 2013; Gaggioli et al., 2019). Understanding how learners feel, think, and invest effort in immersive environments is therefore crucial to evaluating not only usability but also the quality of learning itself.

Accordingly, this study explores how epistemic emotions, absorption, perceived effort, and motivation to learn interact during MetaLab activities. By integrating these constructs, the study extends the MetaLab analysis from *how students use* immersive technologies to *how they experience learning* through them, reinforcing the framework's experiential orientation and linking user experience with the affective and motivational foundations of transformative learning.

3.3 Test and Evaluation Study 3: Epistemic Emotions, Absorption, Effort and Motivation to Learn

In line with the objectives of the *Test and Evaluation* phase, this study examined how university students experienced epistemic emotions, absorption, perceived effort, and motivation to learn during MetaLab sessions implemented in authentic higher education contexts.

The MetaLabs analyzed in this work correspond to those described in "Test and Evaluation Study 2"; however, while the previous study considered all sixteen MetaLabs implemented during the project, the present analysis focuses on fourteen. The rationale for this aggregation and selection is detailed in the *Procedure* section.

3.3.1 Rationale and Objectives

The *MetaLab* framework conceptualizes immersive learning as an experience-driven process in which engagement arises from the dynamic integration of cognitive, emotional, and motivational components (Parrish, Wilson, & Dunlap, 2011; Riva et al., 2016; Gaggioli et al., 2019). Within this perspective, the educational value of XR environments depends less on technological features than on the *quality of the learning experience*, that is, how students feel, focus, and remain motivated during the activity. Building on this experiential orientation, the present study extends the evaluation of MetaLabs beyond user-centered indicators such as usability and workload, focusing instead on the *affective and attentional mechanisms* that shape motivation to learn.

Research in educational and affective psychology highlights the central role of *epistemic emotions*, such as curiosity, enjoyment, and surprise, in promoting cognitive engagement and conceptual change (Pekrun et al., 2017; Muis, Chevrier & Singh, 2018). These emotions emerge from cognitive incongruity or uncertainty and influence learning depending on their regulation: positive activating emotions tend to foster exploration and persistence, while negative emotions like confusion or frustration can either hinder understanding or, when resolved, deepen cognitive processing (D'Mello & Graesser, 2012; Schubert, Pekrun, & Ufer, 2023).

A second experiential component is *absorption*, a key dimension of the flow experience (Csikszentmihalyi & Csikszentmihalyi, 1990; Norsworthy et al., 2023). Absorption reflects deep attentional engagement and loss of self-awareness during task execution, and has been consistently associated with intrinsic motivation, enjoyment, and optimal performance in technology-enhanced learning (Makransky & Petersen, 2021; Johnson-Glenberg, 2018).

Perceived effort complements these affective and attentional dimensions by indexing the subjective demand of the learning task. As suggested by Cognitive Load Theory (Sweller, 2010; Longo & Orrù, 2022), moderate effort supports engagement and persistence, whereas excessive demand may lead to cognitive overload and disengagement.

Together, these constructs converge into the overarching dimension of *motivation to learn*, defined as the willingness to invest effort, attention, and persistence in the learning process (Deci & Ryan, 2000; 2012). Investigating how epistemic emotions, absorption, and perceived effort interact to sustain motivation is essential for understanding how XR-based activities can create engaging, balanced, and pedagogically meaningful learning experiences.

Accordingly, the present study aimed to examine university students' learning experiences during fourteen MetaLab sessions and to assess whether such activities can enhance motivation to learn. Two main objectives guided the investigation:

1. To analyze the relationships among epistemic emotions, absorption, perceived effort, and motivation to learn within MetaLabs.
2. To compare these experiential dimensions across immersive and desktop-based MetaLabs, exploring the influence of modality on emotional engagement, effort, and learning motivation.

By addressing these aims, the study seeks to deepen understanding of the affective and cognitive mechanisms underlying immersive learning and to inform future MetaLab designs that effectively balance emotional engagement and cognitive manageability to foster motivated and transformative educational experiences in higher education.

3.3.2 Theoretical Background

Evaluating XR education requires moving beyond usability or technical performance indicators to consider the *experiential quality* of learning, how learners *feel*, *think*, and *engage* throughout immersive activities. As several authors have noted, traditional metrics such as usability, system efficiency, or task completion rates capture only the functional dimension of technology, overlooking the affective, cognitive, and social dynamics that shape meaningful learning (Laurillard, 2013; Mikropoulos & Natsis, 2011). In immersive contexts, where embodiment, presence, and emotional engagement fundamentally mediate cognition, the learner's *subjective experience* becomes a critical determinant of educational effectiveness (Radianti et al., 2020; Parong & Mayer, 2021a). Riva and colleagues (2016) conceptualize immersive media as "experience technologies," designed not merely to deliver information but to evoke psychological states that support reflection, engagement, and transformation. Similarly, Johnson-Glenberg (2018) argues that evaluations of XR learning environments must account for how learners experience the task, integrating affective and motivational dimensions such as enjoyment, curiosity, and sense of agency. This experiential turn reflects a broader evolution in instructional design, from focusing on the technological usability of learning systems to assessing their capacity to foster engagement, meaning, and personal relevance (Parrish, Wilson, & Dunlap, 2011; Gaggioli et al., 2019).

Epistemic Emotions

From this perspective, *epistemic emotions* constitute a fundamental affective dimension of the learning process, as they directly relate to the individual's engagement with knowledge, understanding, and inquiry. Emerging from the broader framework of the *Control-Value Theory of Achievement Emotions* (Pekrun, 2006), epistemic emotions differ from general achievement emotions (such as pride or shame) in that they are specifically elicited by cognitive activities involving curiosity, exploration, and problem solving (Pekrun et al., 2017). They typically arise in situations characterized by *epistemic uncertainty*, when learners confront gaps in their understanding, inconsistencies in information, or moments of conceptual conflict (Muis, Chevrier & Singh, 2018). In these contexts, emotion functions as a *signal* that something new or unresolved demands cognitive attention, thereby influencing both information processing and motivation.

Positive activating emotions, including *curiosity*, *enjoyment*, and *surprise*, are particularly conducive to deep learning. They promote exploratory behaviors, intrinsic motivation, and cognitive flexibility by broadening the learner's attentional scope and encouraging sustained engagement with the learning material (Muis, Chevrier & Singh, 2018; Vogl et al., 2019). These emotions have been associated with increased use of metacognitive strategies, elaborative processing, and conceptual change, as learners are motivated to reduce uncertainty and construct coherent mental representations (Pekrun et al., 2017). For instance, *curiosity*, defined as a desire for knowledge triggered by information gaps, has been shown to enhance memory retention and understanding, serving as a powerful intrinsic motivator in technology-enhanced environments (Litman, 2005; Kang et al., 2009).

By contrast, *negative activating emotions* such as *confusion*, *frustration*, and *anxiety* play a more complex role. Although they can initially impede performance by taxing cognitive resources or increasing self-doubt, when appropriately regulated they may serve as catalysts for conceptual growth (D'Mello & Graesser, 2012). In their *"confusion–resolution model,"* D'Mello and Graesser (2012) suggest that confusion, when followed by resolution, leads to greater cognitive elaboration and deeper understanding than uniformly positive affective states. Similarly, moderate frustration can motivate learners to persist and refine problem-solving strategies, provided that the level of challenge remains within manageable limits (Kort, Reilly, & Picard, 2001; Schubert, Pekrun, & Ufer, 2023). These findings support the notion that *productive struggle*, a state in which difficulty and emotion coexist, can enhance learning outcomes, particularly in discovery-based or interactive learning environments such as XR.

Finally, *negative deactivating emotions*, notably *boredom*, are typically linked to disengagement, reduced effort, and surface-level processing (Pekrun et al., 2002; Tze, Daniels, & Klassen, 2016). Boredom often arises when learners perceive a lack of challenge, meaning, or personal relevance in the task, leading to attentional withdrawal and motivational decline. In immersive learning, where novelty and interactivity are key, preventing boredom is crucial to maintaining sustained attention and motivation (Makransky & Petersen, 2021).

The *Epistemically Related Emotion Scale* (Pekrun et al., 2017) provides an empirically validated framework to assess these affective states, capturing seven core emotions, enjoyment, curiosity, surprise, confusion, frustration, anxiety, and boredom, each represented by multiple items. The multidimensional structure of the scale allows for distinguishing *positive activating*, *negative activating*, and *negative deactivating* emotions, thereby enabling a nuanced analysis of how specific affective profiles shape cognitive engagement and conceptual change. Integrating this framework within XR research offers a valuable lens for understanding how immersive environments evoke, sustain, and transform the emotional experiences that underlie learning.

Absorption

While epistemic emotions capture the affective quality of learning, *absorption* reflects its attentional and cognitive depth, the degree to which learners become fully engaged and mentally immersed in a task. Originating from the broader construct of *flow* (Csikszentmihalyi & Csikszentmihalyi, 1990), absorption denotes a state of intense focus and psychological involvement in which individuals are so engaged in the activity that they lose awareness of time, external distractions, and even self-consciousness (Norsworthy et al., 2023). This state represents the experiential core of *optimal experience*, a condition that emerges when perceived challenges and personal skills are in dynamic balance. Under such conditions, learning is experienced not as an obligation but as an intrinsically rewarding activity, generating both enjoyment and deep cognitive engagement (Csikszentmihalyi, 2014).

In educational contexts, absorption has been identified as a critical component of meaningful engagement, linking attention, motivation, and emotional investment in learning (Shernoff et al., 2014; Engeser & Rheinberg, 2008). Within the *Psychological Flow Scale* (Norsworthy et al., 2023), absorption is conceptualized as one of the three core dimensions of flow, alongside *enjoyment* and *sense of control*, that together capture the intensity and quality of task engagement. High absorption indicates that the learner's attention is fully anchored in the activity, reflecting not only cognitive focus but also emotional resonance and psychological presence. Such states of deep immersion have been found to enhance learning persistence, increase satisfaction, and support the internalization of knowledge through self-reinforcing cycles of engagement and reward (Fong et al., 2015; Nakamura & Csikszentmihalyi, 2014).

In the context of XR-based education, absorption gains additional relevance due to the sensory and embodied affordances of immersive technologies. Studies have shown that virtual and augmented environments can induce *deep involvement* by combining multimodal stimulation, interactivity, and spatial presence, all of which facilitate attentional capture and sustained engagement (Makransky & Petersen, 2021; Cummings & Bailenson, 2016). The *sense of presence*, the subjective feeling of "being there" in a mediated environment, has been described as both a precondition and a consequence of absorption, reinforcing the attentional focus that underlies flow-like states (Slater, 2003; Riva et al., 2016). When users perceive virtual tasks as both challenging and meaningful, they tend to enter a state of "experiential absorption," characterized by heightened enjoyment, cognitive investment, and a diminished awareness of external demands (Riva et al., 2003; Gaggioli et al., 2019).

Importantly, absorption also mediates the relationship between motivation and performance. Empirical studies have demonstrated that learners experiencing high absorption exhibit stronger intrinsic motivation, greater persistence, and improved problem-solving outcomes compared to those with lower levels of engagement (Moneta, 2012; Shernoff et al., 2014). In technology-enhanced and immersive learning environments, this relationship is particularly evident: when learners perceive a balance between challenge and competence, and when feedback is immediate and meaningful, absorption functions as the psychological mechanism that transforms task difficulty into enjoyment and effort into fulfillment (Wang & Hsu, 2013).

Thus, absorption represents not merely a transient state of concentration but a central experiential marker of effective and transformative learning. It bridges affective activation and cognitive control, embodying the point at which learning becomes intrinsically motivated, emotionally engaging, and optimally demanding. Within the MetaLab framework, analyzing absorption allows researchers to capture the *intensity and quality of attentional engagement* that underpins immersive educational experiences, providing a key lens for understanding how students sustain focus, derive meaning, and achieve a sense of fulfillment in XR-mediated learning.

Perceived Effort

Complementing the affective and attentional dimensions of learning, *perceived effort* serves as a crucial indicator of the cognitive, physical, and emotional energy that learners invest during a task. In immersive environments, effort does not refer solely to mental strain but also encompasses physical and sensorimotor exertion, as learners interact with three-dimensional interfaces, manipulate virtual objects, and perform embodied gestures that require motor coordination and spatial awareness (Makransky & Petersen, 2021). This makes perceived effort a particularly relevant construct for XR education, where cognitive, perceptual, and bodily demands are deeply intertwined. It thus represents the learner's subjective appraisal of total workload, integrating mental concentration, physical activity, and emotional regulation into a unified experiential dimension (Hart & Staveland, 1988; Longo & Orrù, 2022).

Within the framework of *Cognitive Load Theory* (Sweller, 2010), learning effectiveness depends on the efficient management of limited cognitive resources among *intrinsic*, *extraneous*, and *germane* loads. Yet, in XR-based learning, these traditional distinctions often overlap with additional *perceptual* and *motor* loads derived from embodied interaction and multisensory feedback (Makransky et al., 2019). In this context, perceived effort captures the learner's holistic sense of how demanding the experience is, offering insight into whether the immersive activity supports smooth cognitive integration or induces overload. Moderate levels of effort typically correspond to *productive engagement*, signaling that the learner perceives the challenge as demanding yet achievable, thereby sustaining motivation, focus, and satisfaction (Csikszentmihalyi, 2014; Engeser & Rheinberg, 2008). Conversely, excessive effort, whether mental or physical, may lead to *cognitive fatigue*, attentional depletion, and eventual disengagement (Paas & van Merriënboer, 2020), while insufficient effort may indicate under-stimulation or task disengagement (Pekrun et al., 2002).

The multimodal nature of XR learning complicates the regulation of effort. Learners must continuously coordinate *cognitive operations* (e.g., reasoning, memory, decision-making), *perceptual-motor actions* (e.g., head or hand movements, spatial navigation), and *emotional control* (e.g., coping with frustration or curiosity). Well-designed immersive environments tend to balance these demands through intuitive interaction design and clear pedagogical scaffolding, thereby transforming perceived effort into a constructive source of engagement and presence. However, when system responsiveness, visual complexity, or navigation mechanics become cumbersome, total effort increases disproportionately, converting cognitive challenge into workload stress and physical strain (Makransky et al., 2019; Parong & Mayer, 2021a).

To capture this multifaceted phenomenon, the present study adopted the *NASA Task Load Index* (NASA-TLX; Hart & Staveland, 1988), a validated, multidimensional tool widely used to assess subjective workload across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. Given the need to reduce post-immersion fatigue and maintain ecological validity, we focused on the "overall effort" dimension, which asks participants to rate the total amount of effort, mental, physical, and emotional, they invested during the task. The decision to use this single, global indicator of total effort is consistent with recommendations in workload research (Grier, 2015) and with studies in cognitive and educational psychology that employ concise self-report measures of overall cognitive investment (Paas et al., 2003; Longo & Orrù, 2022).

Empirical evidence supports the validity of using the TLX *overall effort* rating as a reliable proxy for total workload in complex, multimodal learning contexts. For example, Longo and Orrù (2022) demonstrated that a single-item global measure effectively captures individual differences in perceived workload in educational and human–machine interaction tasks, while maintaining high convergent validity with the full TLX composite score. Similarly, Makransky, Terkildsen, and Mayer (2019) employed the overall-effort item to detect cognitive and physical strain differences between desktop and immersive VR learning conditions, showing its sensitivity to task complexity and modality effects. In human factors and aviation research, Hart (2006) also confirmed that the Effort subscale correlates strongly ($r > .80$) with overall workload indices, justifying its use when brevity and reduced participant burden are priorities.

This approach aligns with best practices in XR educational research, where the measurement burden must remain low to avoid disrupting the sense of presence, immersion, and post-task recall (Johnson-Glenberg, 2018; Parong & Mayer, 2021a). By focusing on the learner's *subjective total effort*, the study captures how participants integrated all sources of demand, cognitive, perceptual, and physical, into a unified experience of investment.

Interpreted alongside affective and attentional indicators such as *epistemic emotions* and *absorption*, total perceived effort provides a powerful lens for examining how learners regulate energy and attention in response to immersive tasks. Rather than conceptualizing effort as a mere *cost* of learning, this perspective views it as a dynamic allocation of mental and physical resources that reflects the learner's ongoing negotiation between challenge, control, and engagement (Keller, 2009; Riva et al., 2016). In immersive instructional design, understanding how students perceive, and balance total effort is therefore crucial to creating experiences that are cognitively demanding yet emotionally and physically sustainable, maximizing both engagement and learning effectiveness.

Motivation to Learn

Finally, *motivation to learn* represents the overarching construct that integrates emotional, cognitive, and attentional engagement into a unified behavioral disposition toward learning. It can be broadly defined as the learner's *willingness to invest effort, attention, and persistence* in achieving educational goals, reflecting the dynamic interplay between internal drives and contextual affordances (Cook & Artino, 2016). Motivation is not a static trait, but an emergent state shaped by the learner's perceptions of value, control, and self-efficacy during the learning process. Within immersive learning environments, these motivational mechanisms are intensified, as students continuously evaluate both the *meaning* and *manageability* of their experiences in relation to their goals and capabilities (Riva et al., 2016; Zimmerman, 2000).

Among the major theoretical frameworks, *Self-Determination Theory* (SDT; Deci & Ryan, 2012) provides a robust foundation for understanding motivation in XR education. According to SDT, intrinsic motivation, engaging in an activity for its inherent enjoyment and satisfaction, flourishes when three basic psychological needs are met: *autonomy* (a sense of volition and choice), *competence* (a sense of mastery and efficacy), and *relatedness* (a sense of connection with others). XR-based learning experiences are particularly well suited to support these needs. Immersive environments can enhance *autonomy* through active exploration and decision-making; foster *competence* through real-time feedback, scaffolding, and adaptive challenge; and promote *relatedness* through collaborative virtual spaces that strengthen social presence and belonging (Makransky et al., 2020; Riva et al., 2016). When these conditions are fulfilled, learners are more likely to internalize learning goals, experience flow, and sustain engagement over time (Shernoff et al., 2014; Csikszentmihalyi, 2014).

Conversely, when immersive learning environments are poorly designed, offering limited control, insufficient guidance, or excessive cognitive demand, they may frustrate these basic psychological needs, resulting in *controlled* or *amotivation* forms of engagement (Deci & Ryan, 2012). Controlled motivation, driven by external pressures or rewards, can produce temporary compliance but often lacks persistence and personal relevance. In contrast, *amotivation* reflects a state of disconnection or helplessness, where learners perceive little value or efficacy in their efforts (Vallerand, 1997). This underscores the importance of *pedagogical alignment* in XR design: to sustain motivation, immersive activities must balance stimulation with manageability, enabling learners to feel both challenged and supported (Parong & Mayer, 2021a).

Complementary to SDT, the *Expectancy–Value Theory* (Eccles & Wigfield, 2020) emphasizes that motivation depends on learners' beliefs about their ability to succeed (*expectancy*) and the perceived importance or usefulness of the task (*value*). XR environments, by offering vivid, contextualized, and interactive experiences, can enhance both expectancy, by allowing learners to practice and experience success, and value, by making abstract concepts personally meaningful and emotionally resonant (Johnson-Glenberg, 2018; Jensen & Konradsen, 2018). Moreover, immersive experiences that elicit positive activating emotions such as curiosity or enjoyment contribute to the development of *situational interest*, a key antecedent of sustained motivation (Pekrun et al., 2017; Ainley & Hidi, 2014).

In the present study, *motivation to learn* was operationalized through a set of ad-hoc items assessing students' willingness to continue engaging with XR-based learning activities, their perceived educational value of the experience, and their intention to apply what they learned in future contexts. Together with epistemic emotions, absorption, and perceived effort, this construct provides a comprehensive understanding of how affective, cognitive, and attentional mechanisms converge to sustain meaningful and self-determined learning in immersive and non-immersive MetaLab environments.

Taken together, these constructs, epistemic emotions, absorption, perceived effort, and motivation to learn, form a coherent framework for analyzing the quality of students' experiences within MetaLabs. Each dimension captures a distinct yet interrelated facet of immersive learning: emotions reflect affective activation, absorption denotes attentional immersion, effort represents cognitive investment, and motivation encapsulates the enduring drive to engage and persist. Investigating how these dimensions interact across immersive and desktop-based MetaLabs offers valuable insights into the mechanisms that sustain meaningful learning in XR environments. By elucidating these relationships, the present study contributes to advancing the theoretical and empirical understanding of experience-centered learning design in higher education, providing evidence to inform future iterations of the MetaLab framework and the development of pedagogically grounded XR experiences.

3.3.3 Methods

This study employed the evaluation protocol described in Section 2.5, which was developed to assess students' subjective experiences in immersive learning contexts. Although the broader research design originally included two measurement points (pre- and post-experience), the present study focuses exclusively on the post-experience phase. During this stage, participants completed a battery of questionnaires after the MetaLabs assessing key experiential and motivational variables. Specifically, the post-session survey included measures of (i) epistemic emotions, (ii) absorption, (iii) perceived effort and (iv) motivation to learn.

Data collection was conducted anonymously and on a voluntary basis through the Qualtrics online platform. Participants were invited to complete the questionnaires immediately after the MetaLab activity to ensure accuracy of recall and to capture their direct impressions of the immersive learning experience. This timing was chosen to minimize retrospective bias and to preserve the ecological validity of participants' affective and cognitive responses.

All procedures complied with ethical research standards. The study protocol was reviewed and approved by the Ethics Committee for Research in Psychology (C.E.R.P.S.) at the Università Cattolica del Sacro Cuore, Milan, and conducted in accordance with the principles of the Declaration of Helsinki and institutional guidelines governing research involving human participants.

3.3.3.1 Participants

The final sample consisted of 131 university students (N = 67; M_{age} = 23,56 DS_{age} = 5,13; 84%F, 16% M) who took part in one of the fourteen MetaLabs. Among them, 100 students participated in immersive MetaLabs conducted in virtual reality (IVR), while 31 students took part in non-immersive MetaLabs delivered via desktop.

Importantly, the sample consists of the same students that took part in the MetaLabs in study 2 presented before and includes students enrolled in undergraduate, graduate and postgraduate programs across different courses. Although individual demographic variables were not collected in the questionnaire, the heterogeneous composition of the subsample reflects the disciplinary breadth and multidimensional character of the project.

3.3.3.2 Measures

- *Epistemic emotions* were measured using the Epistemically Related Emotion Scale (Pekrun et al., 2017). The instrument consists of 21 items, with three items assessing each of seven emotions typically elicited during learning: enjoyment, curiosity, surprise, frustration, confusion, anxiety, and boredom. Participants rated the extent to which they experienced each emotion during the MetaLab session on a 5-point Likert scale (1 = not at all, 5 = very strongly). Following the categorization proposed by Schubert et al. (2023), items were grouped into three higher-order dimensions: Positive Activating Emotions (*PAE*; enjoyment, curiosity, surprise; α = .84, ω = .85), Negative Activating Emotions (*NAE*; frustration, confusion, anxiety; α = .85, ω = .86), and Negative Deactivating Emotions (*NDE*; boredom; α = .77, ω = .77). A sample item is "I felt curious about what was going on." Higher scores indicate stronger experience of the respective emotional dimension.

- *Absorption (ABS)* was assessed using the Absorption subscale of the Psychological Flow Scale (Norsworthy et al., 2023). This subscale captures the degree of deep concentration, temporal distortion, and immersion experienced during the task (e.g., "I was completely absorbed in what I was doing"). Responses were collected on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Reliability was satisfactory (α = .79, ω = .81).
- *Perceived effort (EFF)* was measured with a single item adapted from the NASA Task Load Index (NASA-TLX; Longo & Orrù, 2022), assessing the overall cognitive and physical effort perceived during the MetaLab activity ("How much effort did you put into performing the task?"). Responses were recorded on a 10-point scale ranging from 1 (very low) to 10 (very high), with higher scores indicating greater perceived workload.
- *Motivation to learn (MTL)* was assessed using four ad hoc items developed for the present study to evaluate participants' interest, engagement, and willingness to continue learning after the MetaLab session (e.g., "This activity increased my motivation to learn more about the topic"). Responses were provided on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The scale showed good internal consistency (α = .85, ω = .85).

3.3.3.3 Procedure

Data was collected at the end of each MetaLab session. As described before, each MetaLab incorporated different instructional activities, such as interactions in metaverse environments, asynchronous avatar-based group work, and experiential simulations, using a variety of XR technologies, including immersive virtual reality (IVR) and non-immersive solutions (desktop, tablets and mobile devices).

To facilitate subsequent analyses, a categorical variable was created in the dataset to classify the type of MetaLab developed. Based on this categorization, MetaLabs were grouped into *immersive* and *non-immersive* (Tab. 17). Immersive MetaLabs referred to learning experiences developed and perceived through virtual reality technologies. In contrast, non-immersive MetaLabs were developed using desktop-based or traditional digital tools, where the learning experience was mediated through a standard screen interface. This classification enabled systematic comparisons between immersive and non-immersive approaches to extended learning.

While the previous study included all sixteen MetaLabs implemented during the project, the present analysis focuses on fourteen. One *hybrid* MetaLab, where participants first completed the learning experience in desktop mode and subsequently in IVR, was excluded due to its small sample size (n=10), which prevented meaningful comparisons with the other two conditions (immersive and non-immersive). Additionally, one experience related to the *Master in Sustainable Business Administration* was discarded because data were not collected for that session.

Tab. 17. Summary information of the MetaLabs

MetaLab type	**Course**	**Campus**	**MetaLab Concept**
Immersive	Sociology of Digital Media	Milan	Visualization of concepts related to the VR medium and virtuality-reality continuum on *Spatial* app with *IVR*.
Immersive	English for Psychology	Brescia	Use of *IVR* and the *Virtual Speech* app for public speaking simulations in English.
Immersive	General Psychology	Piacenza	Use of *Spatial* app and *IVR* to perform a series of interactive minigames about general psychology constructs (e.g., memory, attention, motivation).
Non-immersive	Analytical Chemistry	Piacenza	Desktop-based simulation of chemistry laboratory experiments using *Labster app*.
Non-immersive	Analytical Chemistry	Cremona	Desktop-based simulation of chemistry laboratory experiments using *Labster app*.
Non-immersive	History of Contemporary Architecture	Milan	Use of *Matterport* technology to explore Casa Batlló in a virtual environment.
Immersive	Methods and Techniques of Human Resource Management	Milan	Use of the *BecomeVR* app for a corporate well-being training experience.
Immersive	Institutions of Political Economy	Brescia	Immersive simulation in *Spatial* with *IVR* of the Tragedy of the Commons to explain concepts related to economics and sustainability.
Data non-collected	Master in Sustainable Business Administration (pt.1)	Milan	Use of *IVR* and the *Eye in the Storm* app to explore themes of natural disasters and sustainability.
Non-immersive	Master in Sustainable Business Administration (pt. 2)	Milan	*Desktop-based* simulation on *Spatial* app of a United Nations session addressing sustainability issues.

Immersive	Psychology of New Technologies: Risks and Opportunities for Self and Relationships	Brescia	Visualization of concepts related to the VR medium and virtuality-reality continuum on *Spatial* app with *IVR* to discuss about risks and potentials of XR technologies.
Hybrid	Institutions of Film History	Milan	Visualization of the main milestones in the history of cinema in the *Spatial* app via *desktop* and observation of the immersive short film *The Line* via *IVR* to discuss new cinematic styles.
Immersive	Well-being, Empowerment and Positive Technologies	Milan	Visualization of concepts related to the VR medium and virtuality-reality continuum on *Spatial* app with *IVR* to discuss about XR well-being solutions.
Immersive	General Psychology Laboratory	Milan	Use of *IVR* and the *VirtualSpeech* app for practicing empathic communication skills.
Immersive	Geography (with Laboratory)	Milan	Use of the *Wander* app via IVR to explore key locations from a virtual walk through Milan's Chinatown, focusing on urban transformation.
Non-immersive	Geography (with Laboratory)	online	Exploration of the same urban walk via *Google Street View* via desktop to analyze processes of urban transformation.

The following image presents a selection of settings from two MetaLabs, one implemented using immersive technologies and the other through a desktop-based environment (Fig. 32).

a b

Fig. 32. MetaLab settings. Fig. 32a depicts the Institutions of Political Economy MetaLab (Brescia), while Fig. 32b illustrates the Master in Sustainable Business Administration (Part 2) MetaLab (Milan).

3.3.3.4 Data Analysis

To streamline the analysis of epistemic emotions, the dataset was reorganized according to Pekrun's Valence × Activation taxonomy of emotions (Schubert, Pekrun & Ufer, 2023). Specifically, subscales were grouped into broader categories reflecting their valence (i.e., positive *vs*. negative) and activation level (i.e., activating *vs*. deactivating). Following this framework, the category of *positive activating emotions* included enjoyment, curiosity, and surprise; *negative activating emotions* encompassed confusion, frustration, and anxiety, while *negative deactivating emotions* were represented solely by boredom. This classification allowed for a more parsimonious and theoretically grounded structure of the dataset, facilitating subsequent analyses on the role of epistemic emotions in learning contexts. Furthermore, reliability analyses were conducted for these grouped items as well as for the remaining scales, to ensure internal consistency of the measures. The only exception was the variable *total effort*, for which reliability was not computed since it was measured through a single item.

Descriptive analyses (i.e., means and standard deviations) were conducted separately for the two experimental groups (immersive *vs.* non-immersive) to provide a preliminary overview of data distribution and group-level differences. This step allowed for a clearer examination of central tendency and variability within each condition prior to conducting inferential analyses. Importantly, subsequent analyses were also performed separately for the two types of MetaLabs to ensure a comprehensive understanding of group-specific patterns before comparing variables across conditions.

Then, bivariate *correlation analyses* were conducted to explore associations among the variables within each experimental group (immersive *vs.* non-immersive). Given that the assumptions of normality were met for the immersive condition, Pearson's correlations were applied; for the non-immersive condition, where data distributions were slightly non-normal, Spearman's rank correlations were used.

To examine the predictive role of emotional variables on motivation to learn, multiple *linear regression analyses* were performed separately for immersive and non-immersive experimental groups. In each model, MTL was entered as the dependent variable, and PAE, NAE, and NDE were included as predictors. This approach allowed identification of which types of epistemic emotions significantly contributed to learning motivation in each learning modality.

Finally, *Welch's t-test analyses* were conducted to compare the two experimental groups (immersive *vs.* non-immersive). on each of the six variables (MTL, PAE, NAE, NDE, ABS, EFF). This test was selected to account for unequal variances and different group sizes between conditions.

All analyses were performed using Jamovi (v. 2.7.9) and SPSS. Statistical significance was set at $p < .05$.

3.3.4 Results

Descriptive Analyses

Tab. 18 presents descriptive statistics for the key study variables across immersive and non-immersive MetaLabs.

In immersive MetaLabs, students reported moderate *motivation to learn* (MTL; M = 3.60, SD = 0.71) and relatively high levels of *positive activating emotions* (PAE; M = 3.38, SD = 0.56), accompanied by low *negative emotions*, both activating (NAE; M = 1.97, SD = 0.62) and deactivating (NDE; M = 1.61, SD = 0.71). *Absorption* (ABS) scores were high (M = 3.92, SD = 0.68), indicating that participants tended to experience a state of deep engagement during the activity. *Perceived effort* (EFF) was moderate (M = 2.96, SD = 1.02), suggesting that the immersive experience required both cognitive and physical resources.

In contrast, students in the non-immersive MetaLabs showed higher *motivation to learn* (M = 4.08, SD = 0.55) and slightly higher *positive activating emotions* (M = 3.49, SD = 0.62), combined with lower *negative emotional activation* (NAE; M = 1.66, SD = 0.64) and similar levels of negative deactivation (NDE; M = 1.51, SD = 0.56). *Absorption* remained high (M = 3.78, SD = 0.86), while perceived effort was lower (M = 2.55, SD = 0.77), suggesting that the non-immersive tasks were experienced as less demanding.

Overall, these descriptive trends suggest that non-immersive MetaLabs elicited higher motivation and lower perceived effort, while immersive MetaLabs fostered greater emotional arousal and experiential engagement, consistent with the affordances of immersive environments.

Tab. 18. Descriptive statistics for immersive and non-immersive MetaLabs.

Immersive MetaLabs (N=100)		Non-Immersive MetaLabs (N=31)
	Mean (SD)	*Mean (SD)*
MTL	3.60 (0.71)	4.08 (0.55)
PAE	3.38 (0.56)	3.49 (0.62)
NAE	1.97 (0.62)	1.66 (0.64)
NDE	1.61 (0.71)	1.51 (0.56)
ABS	3.92 (0.68)	3.78 (0.86)
EFF	2.96 (1.02)	2.55 (0.77)

Correlation Analyses

In immersive MetaLabs (Tab. 19), correlations show that:

- Motivation to learn (MTL) had a moderate positive correlation with positive activating emotions (PAE; r = .46, p < .001).
- Motivation to learn (MTL) also was significantly corelated with both types of negative emotions, activating (NAE; r = –.28, p < .05) and deactivating (NDE; r = –.35, p < .01).

This pattern suggests that students who experienced higher enjoyment, curiosity, and surprise tended to feel more motivated, while frustration, anxiety, and boredom were inversely related to motivation.

- Positive activating emotions (PAE) were positively correlated with absorption (ABS; r = .34, p < .001), indicating that emotional activation supported deeper engagement in the immersive environment.
- Notably, negative emotions were interrelated (NAE–NDE: r = .59, p < .001), reflecting an overall dimension of emotional discomfort.

- Perceived effort (EFF) correlated positively with both activating and deactivating negative emotions (NAE; $r = .45$, $p < .001$) and (NDE; $r = .23$, $p < .01$), respectively, suggesting that effort was associated with emotional strain rather than motivation.

Tab. 19. Pearson correlations among study variables – Immersive MetaLabs.

	MTL	*PAE*	*NAE*	*NDE*	*ABS*	*EFF*
MTL	-					
PAE	0.46***	-				
NAE	-0.28*	-0.17	-			
NDE	-0.35**	-0.42**	0.59***	-		
ABS	0.19	0.34***	-0.21*	-0.22*	-	
EFF	-0.17	-0.01	0.45***	0.23**	0.07	-

In non-immersive MetaLabs (Tab. 20):

- Motivation to learn (MTL) was strongly correlated with positive activating emotions ($\rho = .56$, $p < .001$), but not with negative ones.
- Unlike in the immersive condition, no significant relationship appeared between effort (EFF) and emotional variables, indicating a more neutral emotional profile in non-immersive MetaLabs.
- Absorption (ABS) was again positively associated with Positive activating emotions (PAE; $\rho = .53$, $p < .001$), confirming that emotional engagement was a key predictor of focused involvement.

Tab. 20. Spearman correlations among study variables – Non-Immersive MetaLabs.

	MTL	*PAE*	*NAE*	*NDE*	*ABS*	*EFF*
MTL	-					
PAE	0.56***	-				
NAE	-0.02	0.02	-			
NDE	-0.15	-0.28	0.72***	-		
ABS	0.31	0.53***	-0.39*	-0.54*	-	
EFF	-0.02	-0.20	0.27	0.01	-0.01	-

Linear Regression Analyses

To identify the predictors of motivation to learn (MTL), multiple regression analyses were performed for both immersive and non-immersive MetaLabs.

In immersive MetaLabs, positive activating emotions (PAE) emerged as a significant positive predictor of motivation ($\beta = 0.50$, $t = 4.07$, $p < .001$), while neither activating nor deactivating negative emotions contributed significantly. The model explained 26% of the variance in motivation ($R^2 = .26$) (Tab. 21).

Tab. 21. Regression models predicting motivation to learn (MTL) from emotional variables – Immersive MetaLabs.

Predictor	*Estimate*	*SE*	*t*	*p*
Intercept	2.41	0.51	4.68	<.001
PAE	0.50	0.12	4.07	<.001
NAE	-0.18	0.13	-1.44	n.s.
NDE	-0.09	0.12	-0.78	n.s.
$R^2 = 0.26$				

In non-immersive MetaLabs, PAE again significantly predicted motivation ($\beta = 0.53$, $t = 3.99$, $p < .001$), explaining an even larger proportion of variance ($R^2 = .35$) (Tab. 22).

Tab. 22. Regression models predicting motivation to learn (MTL) from emotional variables – Non-immersive MetaLabs

Predictor	*Estimate*	*SE*	*t*	*p*
Intercept	2.23	0.47	4.75	<.001
PAE	0.53	0.13	3.99	<.001
$R^2 = 0.35$				

This finding underscores the consistent role of positive emotional activation in fostering students' motivation across modalities, with slightly stronger predictive power in desktop settings.

Welch's t-test Analyses

Finally, independent samples of Welch's t-tests were conducted to compare immersive and non-immersive MetaLabs (Tab. 23).

The results indicated a significant difference in motivation to learn ($t = 3.91$, $p < .001$), with higher scores in the non-immersive condition. Moreover, participants in the immersive MetaLabs reported higher negative activating emotions ($t = –2.41$, $p < .05$) and greater perceived effort ($t = –2.40$, $p < .05$) than those in the non-immersive group. No significant differences emerged for positive emotions, negative deactivation, or absorption.

Tab. 23. Welch's t-test comparisons between immersive and non-immersive MetaLabs.

	Welch's T	*df*	*p*
MLT	3.91	64.27	<.001
PAE	0.91	46.41	n.s.
NAE	-2.41	48.85	<.05
NDE	-0.83	62.97	n.s.
ABS	-0.80	42.13	n.s.
EFF	-2.40	66.14	<.05

Across both immersive and non-immersive MetaLabs, positive activating emotions (PAE) appeared consistently high and were found to be positively associated with students' motivation to learn (MTL). This pattern may indicate that positive emotional engagement could play a central role in supporting motivational processes within technology-enhanced learning environments, regardless of the level of immersion.

At the same time, the two modalities showed some differences. Students in non-immersive MetaLabs tended to report higher motivation to learn, accompanied by lower levels of negative activating emotions and perceived effort. Conversely, participants in immersive MetaLabs exhibited greater emotional arousal and higher perceived cognitive–physical effort, which might reflect the increased sensory and attentional demands typical of immersive contexts.

No significant differences were observed in positive activating emotions or absorption, both of which remained relatively high across conditions. This consistency suggests that immersive features may not necessarily enhance positive emotions or attentional engagement beyond what is achievable in well-designed desktop-based environments.

Overall, the results suggest that positive emotional activation is likely to be an important predictor of learning motivation in both XR and desktop-based contexts. Nevertheless, non-immersive MetaLabs may provide a more favorable balance between emotional engagement and cognitive manageability, possibly because they elicit similar positive emotions with lower frustration and perceived effort.

3.3.5 Discussion

The present study contributes to the growing body of research examining the affective and motivational mechanisms underpinning learning in XR environments. By integrating epistemic emotions, absorption, perceived effort, and motivation to learn within the MetaLab framework, this investigation provides empirical evidence that supports the central role of emotional activation in sustaining students' motivation across both immersive and non-immersive modalities.

Consistent with prior studies in psychology and technology-enhanced learning (Pekrun et al., 2017; Muis, Chevrier & Singh, 2018; Makransky & Petersen, 2021), the results indicate that positive activating emotions (PAE) are strong predictors of motivation to learn (MTL). In both immersive and desktop-based MetaLabs, students who reported higher levels of these emotions also exhibited greater willingness to continue learning, confirming that affective engagement acts as a catalyst for motivational and cognitive investment (Ainley & Hidi, 2014; Pekrun, 2006).

These findings align with the *Control-Value Theory of Achievement Emotions* (Pekrun, 2006) and extend its applicability to immersive learning contexts. Positive activating emotions (PAE) appear to facilitate students' appraisal of learning tasks as both valuable and manageable, thereby enhancing intrinsic motivation (Deci & Ryan, 2000). This pattern has also been observed in XR studies showing that curiosity and enjoyment mediate the relationship between presence and learning outcomes (Makransky et al., 2020; Parong & Mayer, 2021a). The present results further corroborate the notion that emotional activation, not immersion per se, drives motivational gains, emphasizing the experiential rather than purely technological determinants of engagement (Riva et al., 2016; Gaggioli et al., 2019).

At the same time, the data reveals notable differences between immersive and non-immersive MetaLabs. Students in non-immersive conditions reported higher motivation and lower perceived effort, whereas those in immersive settings experienced greater negative activating emotions and higher workload. This divergence suggests that while immersive technologies can heighten emotional arousal and attentional focus, they may also impose additional cognitive and sensorimotor demands, consistent with findings from *Cognitive Load Theory* applied to XR (Makransky et al., 2019; Longo & Orrù, 2022). Like Parong and Mayer (2021a), who found that fully immersive VR can increase perceived strain without necessarily improving learning outcomes, the present results highlight the need to balance experiential richness with cognitive manageability. In this sense, non-immersive or semi-immersive settings may offer an optimal trade-off between engagement and effort, eliciting comparable levels of positive emotion with reduced frustration and cognitive fatigue.

Interestingly, absorption (ABS) and positive activating emotions (PAE) remained high across both modalities, suggesting that immersive qualities such as presence and attentional focus can be effectively achieved even in desktop environments when instructional design and narrative coherence are strong (Johnson-Glenberg, 2018; Jensen & Konradsen, 2018). This result resonates with research indicating that presence is not solely determined by technological immersion, but by the learner's sense of involvement, agency, and task relevance (Slater, 2003; Riva et al., 2003). Accordingly, the quality of experiential design, how activities scaffold reflection, provide feedback, and integrate emotional meaning, appears to be more critical than the level of sensory immersion alone (Radianti et al., 2020; Gaggioli et al., 2019).

The relationship between negative emotions and effort observed in immersive MetaLabs also deserves attention. The positive correlation between effort and both activating (NAE) and deactivating negative emotions (NDE) suggests that frustration, confusion, or boredom may emerge when immersive experiences exceed students' cognitive or ergonomic comfort zones. However, following D'Mello and Graesser's (2012) "*confusion–resolution*" model, such emotions are not necessarily detrimental: when successfully regulated, they can contribute to deeper processing and conceptual change. This underscores the pedagogical importance of designing XR activities that support emotional regulation through scaffolding, feedback, and progressive challenge. MetaLabs that incorporate explicit debriefing or reflection phases may help transform transient negative arousal into productive engagement, aligning with models of "productive struggle" in experiential learning (Kort, Reilly, & Picard, 2001; Schubert, Pekrun, & Ufer, 2023).

Overall, these findings reinforce the *experiential and constructivist assumptions* underlying the MetaLab framework (Riva et al., 2016; Gaggioli et al., 2019; Parrish, Wilson & Dunlap, 2011). Learning in XR appears to be most effective when cognitive, emotional, and motivational components operate in synergy, when curiosity and enjoyment sustain focus, moderate effort supports persistence, and design scaffolds allow frustration to be resolved constructively. The absence of significant differences in absorption and positive emotions across modalities further suggests that technological immersion is not a prerequisite for affective engagement or motivational gains; rather, these outcomes depend on the quality of pedagogical orchestration and emotional design (Laurillard, 2013).

In conclusion, this study confirms that positive activating emotions are the most consistent predictors of students' motivation to learn across immersive and non-immersive MetaLabs. Immersive modalities enhance emotional arousal and attentional engagement but also increase perceived effort and negative affect, highlighting the need for balanced instructional design. Non-immersive environments, by contrast, may achieve comparable motivational outcomes through emotionally resonant but less demanding experiences. Together, these results support the view that the success of XR education depends less on the degree of immersion than on the intentional design of emotionally rich, cognitively manageable, and pedagogically meaningful experiences.

3.4 General Conclusions

Taken together, the studies conducted within the *Test and Evaluation* phase offer a comprehensive understanding of how immersive learning operates at both a functional and an experiential level within higher education. The three investigations, on "Social, Cognitive, and Affective Experience", "Usability, Effort, and Continuance Intention" and on "Epistemic Emotions, Absorption, Effort, and Motivation to Learn", collectively advance the empirical validation of the MetaLab framework.

The final phase of this doctoral research translates the outcomes of the design-based process into a practical and replicable resource: the *MetaLab Toolkit*. Developed as the culmination of the *Empathize–>Prototype–>Test & Evaluation* cycle, the toolkit synthesizes theoretical principles, methodological procedures, and empirical insights derived from the previous phases into actionable guidelines for educators, instructional designers, and researchers interested in implementing immersive learning environments in higher education.

Within the *Design-Based Research* (DBR) tradition, the creation of design artifacts such as frameworks, models, and toolkits represents a central outcome, as these tangible products encapsulate both theoretical understanding and design knowledge (Anderson & Shattuck, 2012; McKenney & Reeves, 2018). Toolkits are particularly valuable because they transform complex research findings into accessible, evidence-informed resources that support practitioners in making context-sensitive pedagogical and technological decisions (Mor, Craft, & Maina, 2015; Goodyear & Dimitriadis, 2013).

Recent years have witnessed the development of several instructional design toolkits aimed at bridging the gap between research and practice. For instance, the *Learning Designer Toolkit* (Laurillard et al., 2018) enables educators to model, visualize, and share learning designs grounded in pedagogical theory. Similarly, the *CoDesignS Learning Design Framework* (Cukurova et al., 2020) provides structured guidance for co-designing technology-enhanced learning experiences through participatory workshops. In the domain of extended reality, the *EDUCAUSE XR Design Toolkit* (EDUCAUSE, 2022) and the *OpenXR for Education Framework* (Abeywardena, 2023) have outlined principles and templates to support scalable, inclusive, and sustainable XR implementations.

4. Guidelines for Educators and Designers: the MetaLab Toolkit

Building upon these precedent Chapters, the *MetaLab Toolkit* (Fig. 33) aims to operationalize the instructional design model developed in this research by offering a structured set of guidelines, templates, and exemplars derived from the MetaLabs implemented across university contexts. The toolkit serves both as a reflective synthesis of the DBR process and as a practical resource to support the replication, adaptation, and continuous improvement of immersive learning initiatives.

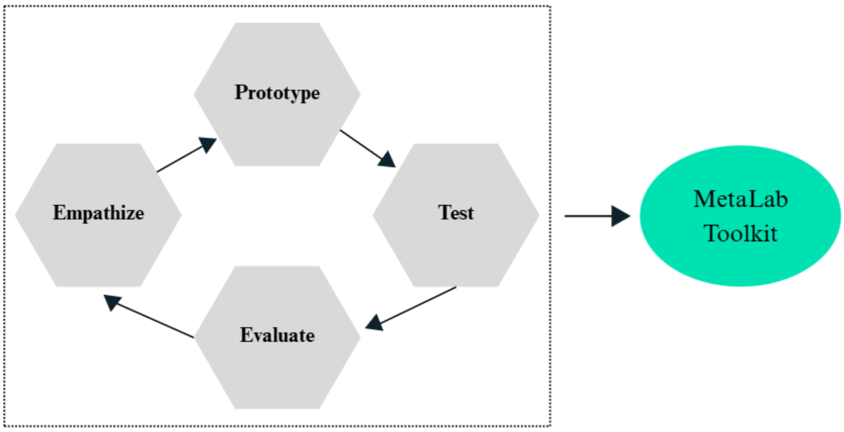


Fig. 33. The MetaLab Toolkit as an outcome of the Design-Based Research (DBR) and Design Thinking (DT) process of the present doctoral work.

4.1 Evidence-Informed Design Guidelines

The guidelines presented in this section derive directly from the empirical findings discussed in Chapter 3. Consistent with the *Design-Based Research* and *Design Thinking* paradigm, these recommendations transform data-driven insights into practical design principles that can inform the creation of future immersive learning experiences (McKenney & Reeves, 2018; Bielaczyc, 2013).

Four main domains emerged from the *Test & Evaluation* phase of the MetaLab project:

- The *social, cognitive, and affective* dimensions of immersive learning.
- The *usability, effort, and continuance intention* dimensions of immersive learning.
- The *epistemic emotions, absorption, and motivation to learn* dimensions of immersive learning.
- The *accessibility and inclusivity in XR education*.

Each of these domains generated specific *design implications*, which have been synthesized into corresponding guidelines within the *MetaLab Toolkit*. Collectively, these guidelines aim to support educators and designers in creating XR-based learning environments that are not only engaging and pedagogically coherent but also psychologically informed, accessible, equitable, and scalable across diverse institutional and learner contexts. The following sections illustrate how the empirical evidence gathered across the MetaLabs has been translated into design-oriented knowledge, providing concrete pathways for integrating psychological and ethical considerations into the instructional design of immersive experiences.

4.1.1 Designing for Engaging, Usable, and Emotionally Resonant XR Learning

4.1.1.1 Rationale

The design of XR learning experiences requires a multidimensional understanding of how students interact cognitively, emotionally, and socially with technology. Evidence from the MetaLab studies demonstrates that the quality of learning experiences in XR depends on the interplay between engagement, usability, emotional regulation, and motivation. These results converge with theoretical frameworks that conceptualize learning as a holistic process involving cognitive processing, affective activation, and social participation (Fredricks et al., 2004; Garrison & Arbaugh, 2007; Pekrun, 2006). Accordingly, three interrelated clusters (i) *social, cognitive, and affective engagement*, (ii) *usability, effort, and continuance intention*, and (iii) *epistemic emotions, absorption, and motivation to learn*, provide a comprehensive rationale for inclusive and evidence-based instructional design in XR.

4.1.1.2 Models and Frameworks

The first cluster focuses on the intertwined processes that sustain engagement in immersive education. In the first study presented in Chapter 3 (*see* "Test and Evaluation: Social, Cognitive, and Affective Experience in Two MetaLabs"), results revealed that immersive conditions fostered higher levels of social presence, cognitive engagement, and positive activating emotions, confirming that embodiment and co-presence intensify learners' sense of connection and investment. These findings align with the Community of Inquiry (CoI) framework (Garrison & Arbaugh, 2007), which posits that *social*, *cognitive*, and *teaching presence* interact to produce meaningful learning experiences, and with Presence Theory (Short et al., 1976; Biocca, Harms & Burgoon, 2003), which interprets immersion as a social–psychological phenomenon of shared attention and co-located interaction.

Cognitive engagement, as shown in the MetaLab data, is modulated by the clarity of task structure and cognitive manageability, consistent with Cognitive Load Theory (Sweller, 2010) and Cognitive Theory of Multimedia Learning (Mayer, 2005). When XR activities were segmented into discrete learning steps, students reported greater focus and conceptual clarity, suggesting that *structured interactivity* mitigates overload (Makransky et al., 2019). At the affective level, the presence of positive activating emotions (enjoyment, curiosity, surprise) correlated strongly with motivation to learn, reinforcing Pekrun's Control-Value Theory (2006), which highlights the reciprocal influence between perceived control, emotional valence, and learning effort. Collectively, these results indicate that XR engagement emerges from a balance between *social belonging*, *cognitive structure*, and *affective stimulation*, a triad essential to the MetaLab design model.

In the second study presented in Chapter 3 (*see* "Test and Evaluation: Usability, Effort, and Continuance Intention in Sixteen MetaLabs"), provided insight into the pragmatic and motivational underpinnings of XR engagement. Across both immersive and non-immersive MetaLabs, perceived usability and effort significantly predicted continuance intention, confirming the mechanisms theorized in the Extended Expectation-Confirmation Model (EECM) (Bhattacherjee, 2001; Lee, 2010; Makransky & Petersen, 2021). When the immersive interface was intuitive, responsive, and predictable, learners reported lower perceived effort and stronger willingness to reuse XR for future learning. Conversely, ergonomic friction, complex menus, uncalibrated controls, or physical discomfort, produced frustration and fatigue, reducing engagement. These findings emphasize that usability in XR is not merely a technical feature but a *pedagogical condition*: effort and satisfaction co-determine the learner's decision to persist. The results also resonate with Technology Acceptance Models (Venkatesh et al., 2003) and the User Experience (UX) framework (Brooke, 1996), which link satisfaction, ease of use, and trust in the system to long-term adoption. In the educational context, designing for usability and comfort therefore means designing for *cognitive economy*—ensuring that the energy learners invest goes into understanding rather than navigating the interface.

In the third study presented in Chapter 3 (see "Test and Evaluation: Epistemic Emotions, Absorption, and Motivation to Learn in Fourteen MetaLabs"), further illuminates the affective–motivational core of immersive learning. The results showed that positive epistemic emotions (enjoyment, curiosity, surprise) were positively associated with absorption and motivation to learn, whereas negative deactivating emotions (boredom, frustration) correlated with higher cognitive effort and disengagement. These relationships are theoretically grounded in Control-Value Theory (Pekrun, 2006) and supported by recent studies on *epistemic emotions in immersive contexts* (Schubert et al., 2023; Lin et al., 2024), which describe curiosity and enjoyment as affective pathways toward intrinsic motivation. Absorption, the sense of total involvement, was found to mediate the relationship between presence and motivation, echoing Flow Theory (Csikszentmihalyi & Csikszentmihalyi, 1990) and related models of Networked Flow (Gaggioli et al., 2017), according to which optimal experience arises when challenges are balanced with skills and supported by feedback. The MetaLab results confirmed that immersive activities fostering exploration and autonomy generated higher absorption and sustained interest. This aligns with Self-Determination Theory (SDT) (Deci & Ryan, 2012), which identifies autonomy, competence, and relatedness as key drivers of intrinsic motivation. Collectively, these findings underscore that emotional design is not peripheral to learning but central to maintaining engagement and intention to reuse XR technologies.

4.1.1.3 Evidence-Informed Guidelines

Building on these converging insights, from theoretical frameworks and empirical results across the MetaLab studies, the following guidelines synthesize practical strategies for designing XR experiences that are cognitively efficient, emotionally resonant, socially inclusive, and sustainable over time.

Cognitive Optimization

Findings from the first MetaLab study demonstrated that students' cognitive engagement increases when XR activities are structured into clear, sequential phases supported by multimodal scaffolding. This is consistent with a large body of research applying Cognitive Load Theory (Sweller, 2010) and the Cognitive Theory of Multimedia Learning (Mayer, 2005) to immersive contexts. For example, Parong and Mayer (2021a) found that breaking VR learning tasks into short, guided segments significantly improved retention and transfer compared to continuous exposure. Similarly, Makransky et al. (2019) reported that learners experienced lower extraneous load and higher conceptual understanding when multimodal cues (e.g., voice narration + visual labels) were used to focus attention on relevant information.

To translate these insights into design practice, immersive lessons should be divided into discrete, goal-oriented units, each with explicit objectives and pacing cues. Multimodal scaffolding, synchronized use of text, narration, and gesture prompts—helps integrate sensory channels and prevent redundancy. Incorporating reflection pauses or micro-assessments between immersive segments facilitates schema construction and long-term retention (Makransky & Petersen, 2021). Finally, the removal of non-essential sensory stimuli (e.g., background music, dynamic lighting, or unrelated objects) reduces cognitive overload and fatigue, as also demonstrated in usability research on VR-based anatomy learning (Küçük et al., 2016) and chemistry simulations (Makransky et al., 2021).

Overall, the literature supports the MetaLab findings: cognitive optimization in XR is achieved not by reducing sensory richness, but by structuring it to support *manageable complexity* and meaningful reflection.

Emotional Regulation

Across the MetaLab studies, curiosity, enjoyment, and surprise were found to be key predictors of motivation to learn, confirming that affective design is central to immersive education. This observation resonates with Pekrun's Control-Value Theory (2006) and with evidence from Parong & Mayer (2021a) and Lin et al. (2024), who reported that curiosity-driven tasks and adaptive challenge levels in VR increased positive epistemic emotions and learning outcomes.

To promote sustained engagement, XR activities should embed curiosity-driven exploration, allowing learners to manipulate, discover, and self-direct their paths through virtual content. Adaptive difficulty mechanisms, where task complexity evolves based on learner performance, help maintain the flow state conceptualized by Csikszentmihalyi & Csikszentmihalyi (1990) and empirically validated in XR learning by Gaggioli et al. (2017).

Affective feedback, such as color transitions, sound cues, or voice-based encouragement, can normalize error and reinforce self-efficacy, as demonstrated by Smith et al. (2023) in studies of VR skill training. Moreover, the balance between activation and rest, recommended in Ramaseri Chandra et al. (2022) and Kourtesis et al. (2024), is essential to avoid emotional overload and cybersickness. Encouraging reflection on emotional experience through structured debriefs or post-session emotion mapping (Schubert et al., 2023) enhances metacognitive regulation and emotional literacy.

Together, these approaches echo a broader shift toward *affective learning design* in XR: one that recognizes emotional regulation as integral to cognitive efficiency and motivational continuity.

Social Facilitation

The MetaLab evidence indicated that social presence and collaborative interaction significantly enhanced both affective engagement and motivation. This aligns with previous studies using the Community of Inquiry framework (Garrison & Arbaugh, 2007) in VR classrooms, where Oh, Bailenson & Welch (2018) and Radianti et al. (2020) found that shared virtual spaces fostered collaboration, accountability, and deeper learning. Similarly, Bailenson (2018) and Freina & Ott (2015) observed that embodied avatars and synchronous manipulation of 3D objects heightened mutual awareness and group cohesion.

To reproduce these benefits, XR environments should be designed to facilitate co-presence through shared problem-solving and synchronized tools (e.g., collaborative object manipulation, shared annotations). Offering multiple communication channels (voice, text, gestures) supports neurodiverse learners and reduces communicative anxiety (Clouder et al., 2020; Beaux et al., 2024). Structured debriefing, guided group reflection after immersive tasks, has been shown to improve learning transfer and empathy (Gaggioli et al., 2024). Furthermore, creating inclusive participation norms and allowing *opt-in anonymity* can lower barriers for students reluctant to self-disclose or dominate interactions (Wakeman et al., 2022).

Comparable findings have emerged from projects such as VR-Learning Spaces (Han et al., 2022) at Stanford University, where structured collaboration protocols significantly enhanced reflective dialogue and motivation. These convergent results reinforce the idea that *social architecture*, rather than mere connectivity, determines the educational value of immersion.

Usability and Effort Management

The second MetaLab study confirmed that intuitive interaction and physical comfort predict both satisfaction and continuance intention in XR. Similar findings appear in Makransky & Petersen (2021), who demonstrated that perceived usability directly affects motivation and learning outcomes, and in Abeywardena (2023), who's *Open XR for Education Framework (OXREF)* emphasizes interoperability, accessibility, and low-threshold interfaces as enablers of sustainability.

Practical design priorities include remappable and alternative input options (voice, gaze, or single-controller modes), recommended also in Killough et al. (2024) as critical for neurodiverse and physically diverse users. Support for multiple postures and locomotion styles, including teleportation and snap-turning, reduces motion sickness and enhances comfort (Stauffert et al., 2020). XR sessions should be fatigue-aware, organized in short, clearly bound modules with optional breaks and calibration pauses, an approach also supported by Jensen & Konradsen (2018), who showed that short exposure cycles improve attention and retention.

Effort should be treated as both a usability and learning metric: as the MetaLab data showed, excessive cognitive or physical effort correlates with frustration and reduced persistence. This finding mirrors results from Steed et al. (2021) and Radianti et al. (2020), who advocate ergonomic testing and *human-centered XR* *evaluation* as part of instructional design. Collectively, these studies establish that usability and comfort are not auxiliary concerns but central determinants of equity and engagement in immersive education.

Motivation and Continuance Intention

Finally, findings from the third MetaLab study highlighted that positive epistemic emotions, absorption, and perceived autonomy predict motivation to learn and intention to reuse XR experiences, patterns consistent with Self-Determination Theory (SDT; Deci & Ryan, 2012) and Flow Theory (Csikszentmihalyi & Csikszentmihalyi, 1990). Similar relationships were reported by Makransky & Petersen (2021), who found that perceived competence and autonomy mediate the effects of presence on learning outcomes, and by Durgungoz & Durgungoz (2025), who showed that intrinsic motivation increases when learners can regulate pacing and modality of participation.

To operationalize these findings, XR experiences should embed autonomy-supportive structures, giving learners agency in exploration and self-pacing. Providing incremental feedback and progress indicators enhances perceived competence, while collaborative or hybrid options reinforce relatedness by enabling both immersive and non-immersive participation. These principles are reflected in projects such as Virtual Reality for Science Education (Makransky et al., 2020) and Kim & Ryu (2024), who successfully integrated adaptive feedback and multimodal participation in XR learning systems. Continuous monitoring of motivational patterns through mixed-methods data (usage analytics and self-reports) allows designers to iteratively refine experiences and sustain engagement beyond initial exposure.

The table below (Tab. 24) synthesizes key design strategies across the five dimensions (i.e., cognitive, emotional, social, ergonomic, and motivational) described.

Tab. 24. Guidelines for Designing Effective XR Learning Experiences

Design Dimensions	**Key Strategies for XR Learning Design**
Cognitive Optimization	• Segment complex content into short, goal-oriented units. • Use multimodal scaffolding (text, audio, gesture) to guide attention. • Integrate reflection pauses or micro-assessments for consolidation. • Remove non-essential stimuli to minimize extraneous load.
Emotional Regulation	• Embed curiosity-driven exploration and adaptive difficulty to sustain flow. • Provide affective feedback (visual, auditory, haptic) to normalize error and reinforce self-efficacy. • Alternate activation and rest phases to prevent overstimulation. • Encourage reflection on emotions to enhance metacognitive awareness.
Social Facilitation	• Design shared, synchronous tasks to enhance co-presence and collaboration. • Offer multimodal communication (voice, text, gesture). • Conduct structured debriefs to promote reflection and empathy.

	• Establish inclusive norms and allow opt-in anonymity.
Usability & Effort Management	• Provide remappable and alternative inputs (voice, gaze, controller). • Support varied postures and locomotion (seated, standing, teleportation). • Design fatigue-aware sessions with short blocks and breaks. • Treat perceived effort as a pedagogical feedback metric.
Motivation & Continuance Intention	• Embed autonomy, competence, and relatedness. • Provide incremental feedback and visible progress indicators. • Enable hybrid/non-immersive participation options. • Monitor motivation through mixed-methods evaluation.

4.1.2 Designing for Accessibility and Inclusion

4.1.2.1 Rationale

The concept of *inclusivity* in higher education emerged during the late 1990s and early 2000s as universities across the UK, North America, and Australia began to reframe widening participation policies into more systemic commitments to equity and belonging. While earlier policies on *access* largely targeted student recruitment and representation, the notion of *inclusive learning and teaching* extended this focus to the everyday structures of pedagogy, curriculum, and institutional culture (Hockings, 2010). Within this perspective, inclusivity denotes a whole-institution orientation in which pedagogy, assessment, and student-facing services are intentionally designed to enable all learners, across disability, neurotype, socioeconomic background, culture, and language, to participate, belong, and succeed (Hockings, 2010; May & Bridger, 2010). It implies not only the diversification of entry points but also the proactive identification and removal of structural, curricular, and attitudinal barriers that inhibit engagement. This whole-system approach draws on earlier educational theory on *inclusive schooling* (Ainscow, 2005), which advocates the co-construction of learning environments that accommodate diversity as a resource for collective growth rather than as a deviation from the norm. Subsequent contributions expanded this principle to higher education by emphasizing participatory course design and institutional self-auditing mechanisms that center student voice in shaping policies, curricula, and support systems (Bathmaker et al., 2010).

In contrast, *accessibility* refers to the technical and procedural dimensions that make educational environments perceivable, operable, and understandable for users with diverse functional needs. In digital learning contexts, accessibility is typically operationalized through recognized standards such as the Web Content Accessibility Guidelines (WCAG) or Section 508 compliance frameworks (Killough et al., 2024), complemented by reasonable accommodation and support workflows that ensure usability in practice (Seale, 2013).

Whereas inclusivity establishes the normative *why* and *who*, the moral imperative of equity, belonging, and participation, accessibility represents the measurable *how*, the criteria and mechanisms through which inclusivity materializes in platforms, courses, and institutional processes. This conceptual pairing gained traction with the expansion of online and blended learning, where the digital mediation of teaching exposed deep disparities in usability and participation. Over time, accessibility has evolved from a compliance issue, often delegated to disability services, into a design principle embedded within instructional and technological planning. Yet, as Seale (2013) observed, the persistence of *retrofitted* accessibility, addressing barriers only after exclusion occurs, reveals the fragility of institutional approaches that remain reactive rather than anticipatory.

This distinction between inclusivity and accessibility becomes particularly consequential in the context of emerging technologies such as immersive virtual reality (IVR). Neurodivergent and disabled students often encounter compounded barriers spanning social, cognitive, and sensory domains. Learning designs that valorize "active" participation through rapid collaboration or high in-class interactivity may inadvertently exclude those for whom such environments produce overstimulation or social anxiety, leading to isolation and reluctance to seek help where disclosure carries stigma (Bhandari & Rainford, 2023; Clouder et al., 2020; Wakeman et al., 2022). In hybrid or online courses, diminished face-to-face contact and missed synchronous touchpoints can further erode social presence and belonging. Staff misunderstandings of neurodivergent behaviors, coupled with inconsistent institutional procedures, often compound these difficulties and delay effective adjustments (McDowall & Kiseleva, 2024; Nash-Luckenbach & Friedman, 2024). In the digital domain, the problem extends to *design bias*: platforms built on neurotypical defaults, fragmented interfaces, unclear navigation, excessive notifications, and inaccessible multimedia, demand substantial, often invisible "access labor" that heightens cognitive load and emotional fatigue (Adams et al., 2019; Tcherdakoff et al., 2025).

Indeed, when addressing accessibility and inclusion in XR-based learning, it is essential to recognize that the category of "students with disabilities" encompasses a wide range of heterogeneous conditions, each with distinct implications for the design of immersive learning experiences. Disabilities may involve sensory, motor, cognitive, or neurodevelopmental dimensions, and their impact on XR usability and learning effectiveness varies accordingly (Burgstahler & Cory, 2010; Steinfeld & Maisel, 2012). Treating accessibility as a uniform requirement risks overlooking both specific barriers and potential affordances offered by immersive technologies.

From a sensory perspective, students with visual impairments may encounter challenges related to visually dense environments, low contrast, or reliance on spatial cues, while students with hearing impairments may be excluded by XR experiences that depend heavily on auditory feedback. Research suggests that multimodal redundancy, such as combining visual, auditory, and haptic cues, as well as providing captions, alternative representations, and adjustable sensory channels, can mitigate these barriers and support more inclusive learning experiences (Rauschnabel et al., 2022; Radianti et al., 2020). Similarly, XR can offer unique opportunities for sensory substitution or amplification, but only when accessibility is intentionally integrated at the design stage.

Motor disabilities introduce additional constraints related to interaction techniques, locomotion, and physical embodiment. XR experiences that require precise gestures, rapid movements, or prolonged standing may inadvertently exclude learners with limited mobility or motor control. Inclusive XR design therefore benefits from flexible interaction modalities, customizable input methods, and alternatives to physically demanding navigation, such as teleportation or gaze-based interaction (Mottelson et al., 2023; Stanney, Fidopiastis & Foster, 2020).

Cognitive and neurodivergent profiles, including attention disorders, learning disabilities, or autism spectrum conditions, raise further considerations related to cognitive load, sensory overstimulation, predictability, and task structure. While immersive environments can support engagement and experiential understanding, they may also increase extraneous cognitive load if poorly designed. Studies emphasize the importance of clear task scaffolding, gradual onboarding, adjustable complexity, and learner control over pacing and stimulation to ensure that XR supports, rather than hinders, learning for cognitively diverse students (Makransky, Petersen & Immordino-Yang, 2019; Bacca et al., 2014).

Taken together, these considerations highlight the need to approach accessibility in XR learning through the lens of inclusive and universal design, focusing on flexibility, adaptability, and learner choice rather than one-size-fits-all solutions. Rather than designing XR experiences for an abstract “average learner,” inclusive XR pedagogy requires anticipating diversity in sensory, motor, and cognitive functioning and embedding accessibility features from the outset. In this perspective, XR technologies can contribute to more equitable learning environments, if inclusivity is treated as a core design principle rather than a secondary accommodation.

In immersive learning environments, these issues are amplified. IVR systems are typically engineered for users with binocular visual acuity, bimanual controller input, upright mobility, stable vestibular function, and tolerance of intense sensory stimulation, assumptions that systematically exclude or disadvantage many learners. For instance, a student with limited dexterity may find two-controller, simultaneous-grip tasks impossible to perform; a learner with low vision may struggle to read low-contrast microtext or follow purely visual cues; a deaf student may be unable to access speech-only instructions or auditory feedback; wheelchair users may be constrained by interaction heights calibrated for standing participants; and students with vestibular disorders may experience nausea or disorientation during continuous joystick locomotion. Even for neurotypical participants, excessive motion and visual intensity can trigger cybersickness, a well-documented phenomenon affecting between 20% and 80% of VR users (Dużmańska et al., 2018; Kim et al., 2021; Stauffert et al., 2020). Such cases illustrate how the absence of inclusive and accessible design not only marginalizes certain groups but also limits the pedagogical reach of immersive technologies. A hypothetical yet realistic scenario might involve a university course that mandates participation in a VR simulation to complete a graded assignment without providing desktop or non-immersive alternatives. In this case, students with motor or sensory impairments, or those unable to tolerate head-mounted displays due to motion sensitivity, are effectively excluded from full participation, converting a learning innovation into a new gatekeeping mechanism.

Consequently, designing for inclusivity and accessibility in XR education must be viewed not as a corrective measure but as a constitutive principle of educational innovation. Embedding inclusive design at the outset of XR development ensures that immersive learning serves as an enabler of equity rather than a vector of exclusion. In doing so, it repositions accessibility from the margins of institutional practice to the core of pedagogical quality, aligning XR-based instruction with the broader ethical and social mission of higher education.

4.1.2.2 Models and Frameworks

The most influential pedagogical model for embedding inclusivity at the course level is the *Universal Design for Learning (UDL)* framework, an educational adaptation of the broader Universal Design (UD) principles developed in architecture by Ron Mace at North Carolina State University in the 1980s (Mace, 1985; Mace, Hardie, & Place, 1991). Whereas Universal Design in the built environment sought to ensure that physical spaces could be accessed and navigated by the widest possible range of users, through features such as ramps, elevators, tactile paths, or visual signage, UDL extends this ethos to the design of educational environments (Dewi et al., 2019). The underlying philosophy is that barriers reside in design, not in learners, and that equitable participation can only be achieved when variability is anticipated and addressed proactively at the design stage rather than retrofitted through accommodations (Rose et al., 2005).

Initially formalized by Rose, Meyer, and colleagues at the *Center for Applied Special Technology* (CAST) in the late 1990s, UDL provides a theoretical and operational framework for anticipating learner diversity through flexible pedagogical design (Rose et al., 2005). It is grounded in cognitive neuroscience research, which identifies three distinct but interconnected neural networks, recognition, strategic, and affective systems, corresponding respectively to perception and comprehension, action and expression, and motivation and engagement. These systems map onto the framework's three principles: (i) providing multiple means of representation, (ii) multiple means of action and expression, and (iii) multiple means of engagement. Together, they guide educators to offer varied pathways for accessing content, demonstrating knowledge, and sustaining interest (Hitchcock et al., 2016; He, 2014; Katz & Sokal, 2016; Navarro et al., 2016; Spencer, 2011).

In practice, this entails designing courses that are multimodal, flexible, and participatory, thereby improving cognitive and affective engagement for both neurodivergent and neurotypical students (Capp, 2017). UDL thus rejects "one-size-fits-all" instruction and embeds *optionality*, in goals, materials, methods, and assessments, so that each learner can engage with the curriculum through the modalities most compatible with their sensory, cognitive, and emotional profiles.

Within XR education, the UDL framework acquires renewed relevance, as immersive environments expand the representational and experiential channels through which learning can occur, while simultaneously introducing novel accessibility barriers (Al-Azawei, Serenelli, & Lundqvist, 2016; Boothe et al., 2018). Translating UDL to XR contexts therefore requires systematic attention to multimodal accessibility, interaction flexibility, and cognitive load management, dimensions that ensure immersive learning remains equitable, comprehensible, and pedagogically effective (Makransky & Petersen, 2021; Dourda & Papadakis, 2024).

Beyond the scope of individual courses, recent scholarship on *neuroinclusive pedagogical architecture* extends the rationale of UDL to the broader cognitive, emotional, and social ecology of higher education. These approaches recognize that learner variability extends far beyond sensory or physical access to encompass differences in executive functioning, emotional regulation, and social interaction preferences (Clouder et al., 2020; Durgungoz & Durgungoz, 2025). Considering these aspects from the beginning, marks a paradigmatic shift from *reactive* responses (i.e., design to solve a problem) to *anticipatory design*, in which educational systems treat diversity as a design condition rather than an exception (Lewthwaite & Nind, 2016).

From this perspective, inclusivity encompasses not only equitable access to material resources but also psychological safety and affective comfort within learning communities. The notion of *opt-in anonymity*, for example, allows learners to participate in discussions and collaborative tasks without exposing diagnostic or personal information, thereby reducing the stigma often associated with disclosure (Clouder et al., 2020; Wakeman et al., 2022). *Adjustable pacing* acknowledges intra-individual variability in sensory processing and attentional rhythms, enabling learners to regulate the intensity, duration, or sequencing of their engagement, an especially critical feature in immersive and XR-based environments, where visual and vestibular demands fluctuate considerably (Durgungoz & Durgungoz, 2025). Similarly, *multimodal collaboration*, offering students a choice between textual, vocal, gestural, or asynchronous contributions, supports differentiated communication preferences and emotional regulation (Beaux et al., 2024). Collectively, these strategies act as neuroinclusive translations of UDL's "multiple means" principles, extending flexibility from representation and expression to the very act of participation. In this sense, inclusiveness becomes a matter of systemic responsiveness rather than individual adjustment.

At the institutional level, this broader vision of inclusion is embodied in organizational frameworks such as *"access grafting"* (Borsotti et al., 2024), which reconceptualize accessibility as an integral component of institutional governance rather than a peripheral compliance task. Building on critiques of ad-hoc accommodation systems (Seale, 2013), access grafting embeds individualized support practices directly into standard operational workflows, spanning curriculum design, procurement, and quality assurance. Its rationale is twofold: first, systemic inclusion cannot be achieved through isolated interventions, as barriers are often reproduced by the very procedures through which courses and technologies are commissioned and approved (McDowall & Kiseleva, 2024); second, sustainable inclusion requires accountability mechanisms that continuously monitor and refine institutional practice (Nash-Luckenbach & Friedman, 2024). To this end, access grafting formalizes routine, auditable processes, including clearly defined accessibility roles, shared design templates, proactive screening for access needs, and cyclical evaluation, treating accessibility as a dimension of educational quality rather than an afterthought (Borsotti et al., 2024).

Taken together, these frameworks, UDL, neuroinclusive architectures, and access grafting, signal a conceptual and ethical reconfiguration of inclusivity in higher education. Diversity is repositioned from the margins of pedagogy to its structural core, shifting the emphasis from *remediation* to *resilience by design*. This transition is particularly salient in XR and immersive learning, where the same affordances that enrich embodiment and interactivity can also intensify cognitive load and sensory exclusion if uncritically implemented (Makransky & Petersen, 2021).

4.1.2.3 Evidence-Informed Guidelines

Applying the principles of UDL to XR education entails designing immersive experiences that are flexible, multimodal, and responsive to learner variability.

- The principle of *multiple means of representation* can be operationalized through multimodal accessibility, including captions, transcripts, audio descriptions, and scalable high-contrast visual interfaces that make information perceivable across sensory modalities and align with recognized accessibility standards and XR best practices (Götzelmann, 2019; Abeywardena, 2023).
- The principle of *multiple means of action and expression* translates into the provision of alternative and remappable inputs, such as voice commands, eye-gaze with dwell selection, switch control, or single-controller mappings, along with flexible postures (seated, standing, or desktop participation). Adaptive and logically structured interfaces should provide consistent feedback and minimize extraneous cognitive load, supporting learners with different physical and executive functioning profiles (Kim & Ryu, 2024; Makransky et al., 2019).
- Finally, *multiple means of engagement* involve integrating features that sustain motivation and emotional regulation, such as personalized pacing, progressive task difficulty, self-regulation cues, and affectively responsive feedback mechanisms that reduce anxiety and prevent sensory overstimulation (Jensen & Konradsen, 2018; Parong & Mayer, 2021a; Smith et al., 2023).

A notable implementation of these principles is offered by Kim and Ryu (2024), who designed an XR learning module grounded in UDL guidelines. Their system allowed users to customize sensory presentation (e.g., adjustable audio, captions), navigate content via pictogram-plus-text labeling, and interact with a virtual agent through both voice and text inputs. Immediate multimodal feedback fostered metacognitive self-regulation, while hand-tracking enhanced embodiment and engagement. The study highlights both the promise and the practical limitations of such designs: although accessibility and learner adaptability improved, scalability was constrained by device costs and limited infrastructure for large cohorts. These findings underline that inclusivity in XR requires not only instructional but also institutional adoption to ensure sustainability and equity at scale.

Translating these insights into practice requires conceptualizing IVR as one modality among several, rather than a singular pathway to learning outcomes:

- Designers could therefore create dual-mode learning pathways, *immersive and non- or semi-immersive* (i.e., desktop or web equivalents), aligned with the same learning objectives, rubrics, and assessments, and explicitly communicate these options in course syllabi.

Finally, hybrid and flexible participation models, such as accessible lecture recordings, asynchronous equivalents, and varied assessment pathways, can transform digital systems from potential barriers into enablers of parity, particularly for learners with social anxiety, sensory sensitivities, or fluctuating self-regulation capacities (Adams et al., 2019; Beaux et al., 2024; Durgungoz & Durgungoz, 2025; Wakeman et al., 2022). Across these pedagogical and organizational layers, the literature converges on the need for systematic, institution-wide implementation and rigorous mixed-methods evaluation linking specific design features, such as anonymity affordances or dual-mode participation, to outcomes in learning, well-being, and persistence (Clouder et al., 2020; McDowall & Kiseleva, 2024). The overarching transformation is thus from accommodation-as-exception to inclusion-by-design, and from individual advocacy to institutional accountability.

- Evaluation procedures should verify *comparable learning* benefits across modalities to ensure pedagogical parity.
- Interaction design must prioritize *configurability and comfort*, including remappable controls, single-controller and seated interaction options, voice or eye-gaze input, and comfort locomotion features such as teleportation, snap-turn, adjustable movement speed, and dynamic vignette.
- Interfaces should offer reachable menus at variable heights, high-contrast scalable layouts, and meaningful haptic cues, while media accessibility should include captions, transcripts, visual indicators for audio events, and audio description for essential visuals.

At the course level, instructors should administer *pre-session accessibility and inclusivity surveys* to identify available devices, prior VR experience, motion sensitivity, and preferred input methods. Structured onboarding can reduce cognitive load and anxiety, while non-penalizing repair cycles, such as private help channels, re-tries, or extended deadlines, can decouple support from self-disclosure, fostering psychological safety.

At the institutional level, accessibility must be integrated into procurement and governance through formal checklists, requirements for interoperability (e.g., OpenXR standards), built-in captioning and transcript functionalities, and standardized hygiene and fit protocols for shared headsets. Staff training should ensure that accessibility is embedded into the design process rather than retrofitted after implementation (Adams et al., 2019; Beaux et al., 2024; Abeywardena, 2023; Killough et al., 2024).

Given the prevalence of cybersickness as side effect of IVR, which is strongly correlated with general motion-sickness susceptibility and mitigated by prior experience with interactive media, a *comfort-first design approach* is essential. Recommended strategies include minimizing forced vection and rapid accelerations, stabilizing the horizon, implementing progressive exposure and frequent breaks, calibrating headset fit, limiting session duration, and providing clear pause and exit options (Ramaseri Chandra et al., 2022; Kourtesis et al., 2024; Golding et al., 2021; Lukacova et al., 2023; Stauffert et al., 2020; Kim et al., 2021).

4.2 The MetaLab Toolkit for Co-Design

The MetaLab Toolkit for Co-Design acts as a pragmatic bridge between theoretical principles and classroom practice, providing a compact, reusable set of templates, that scaffold the MetaLab co-design process (*see* chapter 2.2.1). This dedicated toolkit systematizes best practices drawn from three years of the Metaversity Project (Gaggioli et al., 2024). By packaging the co-design templates (i.e., profiling, consolidation, testing), the toolkit both reduces the entry costs for instructors and creates comparability across implementations, enabling reproducibility and cumulative learning in a domain that is still largely experimental. Practically, the toolkit supports interdisciplinary workflows (instructors, instructional designers, developers) and embeds formative data collection to fuel DBR cycles. Conceptually, offering a toolkit contributes to the field by translating mid-level theory into actionable design heuristics that can be refined across contexts, thereby accelerating scalable and equitable adoption of XR in higher education (Krüger et al., 2025; Granić, & Marangunić, 2019).

4.2.1 The Profiling Sheet

When: the Profiling Sheet (Tab. 25) is used at the very start of the MetaLab design process, during initial stakeholder engagement (the faculty member, educator etc.), namely, the first co-design workshop (i.e., profiling phase). It is completed before any content authoring or technical prototyping begins.

Purpose: its aim is to create a compact but comprehensive snapshot of the pedagogical, contextual, and logistical constraints that will drive the experience design decisions. The sheet translates high-level course goals into operational requirements, clarifies target learners and accessibility needs, records available infrastructure and devices, and identifies measurable learning outcomes and assessment rubrics.

Tab. 25. The Profiling Sheet

Planned start–end dates for the course *Date avvio-chiusura previste per l'insegnamento*	1° sem. | 2° sem. **MONTHS:** *MESI:*
Instructor name *Nome docente*	
Course title *Nome dell'insegnamento/corso*	
Degree programme *Nome del corso di laurea*	
Campus / location of the course *Sede presso cui si svolge il corso*	

Hours dedicated to teaching *Ore dedicate alla didattica*	
Total number of students *N. studenti totale*	
Average number of students on-site *N. medio studenti in aula*	
Average number of students remote / online *N. medio studenti a distanza*	
Technologies available in the classroom *Tecnologie disponibili in aula*	
Draft: description of the learning objective *Draft: descrizione obiettivo di apprendimento*	
Draft: introduction, activities, debriefing *Bozza: introduzione, svolgimento, debriefing*	
Draft: hardware and software to be used *Bozza: dispositivi hardware e software da usare*	
Other materials *Altri materiali*	
Next steps *Next steps*	

The participatory approach adopted not only facilitates the collection of essential data but also fosters a sense of engagement and ownership among participants, elements that are crucial for the successful implementation of MetaLab solutions in the academic setting.

Link to the Geography example: in the *Virtual Tour of Milan's Chinatown* case (*see* paragraph 2.2.1.1), the Profiling Sheet of Professor Molinari's "Geografy with Laboratory" course (Tab. 26), captured the first learning goals (i.e., students' spatial and sociocultural awareness) and the possibility of designing a dual-mode delivery of the experience (i.e., immersive and non-immersive).

Tab. 26. The Profiling Sheet that was used for the co-design of Geography with Laboratory course.

Planned start–end dates of the teaching for the course *Date avvio-chiusura previste per l'insegnamento*	1° sem. ✖ | 2° sem. ✖ **MONTHS: Feb-May** *MESI*
Instructor name *Nome docente*	Paolo Molinari

Course title *Nome dell'insegnamento/corso*	Geography (with laboratory)
Degree programme *Nome del corso di laurea*	Primary Education Sciences
Campus / location of the course *Sede presso cui si svolge il corso*	Milan / Brescia/ Piacenza
Hours dedicated to teaching *Ore dedicate alla didattica*	Milan: 60 Brescia: 60
Total number of students *N. studenti totale*	Milan: 80 out of 250 (1st sem.), 50–60 (2nd sem.) Brescia: 140 / 250 (1st sem.), 80 / 250 (2nd sem.)
Average number of students on-site *N. medio studenti in aula*	
Average number of students remote / online *N. medio studenti a distanza*	
Technologies available in the classroom *Tecnologie disponibili in aula*	PowerPoint, online polling platform, paper notebooks in class. We also organize field trips.
Draft: description of the learning objective *Draft: descrizione obiettivo di apprendimento*	To find an experience that could be suitable for students from both campus + online to talk about territorial changes. In the past we did: - Milan: excursion to City Life for data collection and landscape experimentation (including olfactory aspects). 2nd Semester. Visited Chinatown for further data collection and landscape experiments. - Brescia: visited a neighborhood to observe the transition between urban and rural areas. - Lake Iseo: explored the place and collected territorial data.
Draft: introduction, activities, debriefing *Bozza: introduzione, svolgimento, debriefing*	We could have an experience that is both immersive and non-immersive. - Use of tablets and mobile phones for low-immersion experiences, focusing on emotional engagement and socialization. Or:

	- Field trips with focus on data collection and direct observation of landscape and urban/ rural transitions. - Non-immersive mode for on-site exploration and experimentation. And (in the laboratory): - Immersive mode to simulate real situations that students of the course (that will mainly interact with primary school children) could face in the future.
Draft: hardware and software to be used *Bozza: dispositivi hardware e software da usare*	
Other materials *Altri materiali*	
Next steps *Next steps*	- Inventory of devices students can bring to the classroom. - Share materials to get an idea of keywords and exercises already implemented.

It is important to note that during the profiling meeting the brainstorming remains at a high level and for many sections of the sheet to be left incomplete or deferred to later meetings. This phase functions as an exploratory space in which inputs, priorities, and constraints are gathered quickly and provisionally: the aim is not to finalize every item but to initiate a shared reflective process. The iterative approach helps ideas to clarify progressively, fostering instructor engagement as the teacher, guided by the ILeaD, moves from a broad vision to a more focused, operational formulation. This process frequently culminates in the identification of a single, well-defined learning objective. The incremental path also strengthens ownership of the project and makes subsequent decisions faster, better informed, and more closely aligned with the real teaching context.

4.2.2 The Prototyping Sheet

When: the Prototyping Sheet (Tab. 27) is employed during the second co-design workshop (i.e., prototype phase).

Purpose: its aim is to support XR platform selection, content selection, and draft the learning design workflow. The sheet crystalizes the most important information (e.g. place where the MetaLab can take place) and learning objectives identified during the initial profiling session. The sheet then presents a section related to the description of the content and the specific activities that will constitute the XR learning experience. To fill this part, a key component of the prototyping meeting is the presentation of examples of virtual environments/

experiences/ platforms that have been developed/ found by technical consultants, such as the Spatial platform[13]. These examples are typically related to platforms designed to be usable in both immersive and non-immersive modes, reflecting the intrinsic flexibility of XR technologies in educational contexts. Last part of the sheet is dedicated to producing a short abstract synthesizing the draft of the MetaLab experience, in order to be used as the foundation for the next design phases and for the third co-design meeting.

Tab. 27. The Prototypying Sheet

Planned date for the MetaLab *Data prevista per il MetaLab*	1° sem. | 2° sem. **MONTHS:** *MESI:*
Instructor name *Nome docente*	
Course title *Nome dell'insegnamento/corso*	
Degree programme *Nome del corso di laurea*	
Campus / location where the MetaLab will take place *Sede presso cui si svolgerà il MetaLab*	
Hours dedicated to MetaLab *Ore dedicate al Metalab*	
Total number of students that can participate to MetaLab *N. studenti totale che potrebbe partecipare al Metalab*	

Final description of the learning objective *Descrizione finale dell'obiettivo di apprendimento*	
Ideas that emerged during the second co-design meeting *Idee emerse nel corso del secondo incontro di co-progettazion*	

[13] As previously described in the present thesis, one example of a platform frequently used in the Metaversity project was Spatial. Spatial is a cross-platform spatial computing environment (accessible via web browser, mobile apps and VR headsets) designed for collaborative, immersive experiences such as virtual classrooms, exhibitions and team workshops. In our implementation, Spatial allowed us to create shared virtual rooms where participants interact via avatars, present and discuss 3D models, images, videos and documents, or use in-space whiteboards and notes for collective reflection. The platform supports importing common 3D and media formats and offers simple in-app tools for arranging, annotating and anchoring objects, so instructors and students can assemble learning scenes and co-create artifacts without advanced programming skills. These content-creation possibilities, combined with spatial audio and persistent room layouts, make Spatial useful both for synchronous hands-on activities and for building persistent MetaLab exhibits that learners can explore and extend over time.

MetaLab content *Contenuto del MetaLab*	
Next steps *Next steps*	

MetaLab Abstract *Abstract del MetaLab* "Please write below an abstract (maximum 500 words) describing the educational experience you intend to create." *"Vi chiediamo adesso di scrivere qui di seguito un abstract di massimo 500 parole in cui descrivere l'idea di esperienza didattica che si vorrebbe realizzare."*	

Link to the Geography example: in the *Virtual Tour of Milan's Chinatown* case, the prototyping template of Professor Molinari's "Geografy with Laboratory" course (Tab. 28), guided the co-design and documentation of the Chinatown virtual tour by structuring key information (e.g., timing, instructors, locations and lab hours), clarifying the shared learning objective, and recording the ideas that emerged during workshops. Using the template, we specified three delivery modalities of the MetaLab experience (i.e., immersive in Milan, semi-immersive in Brescia, and in-person in Piacenza), listed concrete content options (i.e., Spatial.io rooms, 3D models, 360° videos, Google Earth/Street View links) and captured logistical constraints (e.g., group splits for headsets, smartphone or paper alternatives for quizzes). The template also helped translate pedagogical goals into measurable activities and assessment ideas (e.g., spatial recall quizzes, mental maps, photo-based comparisons) and to identify next steps (professor's format proposal, familiarization tasks, and a validation meeting in September). In short, the template served as a compact project ledger that aligned stakeholders, made technical choices explicit, and turned co-design notes into an actionable prototype ready for testing.

Tab. 28. The Prototypying Sheet that was used for the co-design of Geography with Laboratory course.

Planned date for the MetaLab *Data prevista per il MetaLab*	1° sem. | 2° sem. ✖ **MONTHS: Apr-May** *MESI*
Instructor name *Nome docente*	Prof. Paolo Molinari

Course title *Nome dell'insegnamento/corso*	Geography (with laboratory)
Degree programme *Nome del corso di laurea*	Primary Education Sciences
Campus / location where the MetaLab will take place *Sede presso cui si svolgerà il MetaLab*	Milan / online
Hours dedicated to MetaLab *Ore dedicate al Metalab*	2-3
Total number of students that can participate to MetaLab *N. studenti totale che potrebbe partecipare al Metalab*	10-20 approx.

Final description of the learning objective *Descrizione finale dell'obiettivo di apprendimento*	Integrate a real naturalistic experience with a virtual one (more or less immersive). Possibility to carry out field-trip experiences in different modalities: Milano → immersive pathway Brescia → semi-immersive pathway Piacenza → in-person pathway (students from Piacenza will come to Milan).
Ideas that emerged during the second co-design meeting *Idee emerse nel corso del secondo incontro di co-progettazione*	One could use a space within the Spatial.io platform. Apply the method of loci and present content in the virtual space created by Icecubs*. Use the virtual platform to display materials or environments. It is also possible to materialize three-dimensional content (e.g., create or download a small 3D model of Lake Iseo to present within that space). Or Use third-party videos/ apps (e.g., 360° videos) or EarthQuest or Google Earth to visualize environments. Or Use the Spatial.io platform to enter the virtual environment and, within it, create links to Google Street View that can then be accessed. Note: We could consider having an external person connect to demonstrate how telepresence works. If the experience is delivered in immersive mode (with headsets), the class must be split into at least two

	groups (for logistical reasons). It is possible to proceed with the non-immersive mode if the learning objective can still be achieved. *Software partner of the Metaversity project.
MetaLab content *Contenuto del MetaLab*	Create a real journey in Milan Chinatown for bringing students (in person learning experience). Find a VR platform that allows to replicate the same journey to another group (virtual learning experience) and a sei-immersive platform that allows the same experience with less immersive tools. Then, create quizzes to place inside the metaverse space (e.g., recognition and recall tasks targeting spatial memory) and/or present in person. For example, present several maps and ask which map is the correct one. For the quizzes, students could also access a platform via smartphone to complete the exercises or use paper and pencil.
Next steps *Next steps*	- Identify performance indicators. - Meeting in September to validate the prototype.

MetaLab Abstract *Abstract del MetaLab* **“Please write below an abstract (maximum 500 words) describing the educational experience you intend to create.”** *“Vi/ Le chiediamo adesso di scrivere qui di seguito un abstract di massimo 500 parole in cui descrivere l'idea di esperienza didattica che si vorrebbe realizzare.”*	**Title:** Chinatown (Via Paolo Sarpi): Field Trips and Virtual/Hybrid Exploration **Target group and scope:** this laboratory proposal is addressed to students enrolled in the bachelor’s degree in Primary Education at the Milan, Brescia and Piacenza campuses. The activity revolves around a single route through Milan’s Chinatown (Via Paolo Sarpi) and will be delivered through three different modalities to allow a comparative evaluation of learning outcomes: 1. Milan → immersive pathway using headsets/ VR. 2. Brescia → semi-immersive pathway using GIS tools (Google Earth, Google Maps, Google Street View). 3. Piacenza → in-person field visit (students from Piacenza will travel to Milan). Although the mode of delivery differs across sites, all groups will follow the same route and perform

<table>
<tr>
<td></td>
<td>equivalent tasks adapted to each modality. The project was conceived to investigate how a real (on-site) experience and a virtual experience (varying in immersion) can be integrated, and to assess whether and how the intended learning objectives are achieved by comparing outcomes across the three modalities. The overarching aim is to design a playful, educational and socially inclusive learning experience that is affordable and culturally accessible.

Learning objectives:
Recognize and describe the distinctive features of a multicultural neighborhood.
Understand the diachronic evolution of the neighborhood and identify evidence of urban change.
Apply the Geographical Education to the Territory (EaT) method to identify places endowed with specific values, dynamics and properties, with the aim of protecting and enhancing cultural diversity and fostering active, responsible citizenship (e.g., locating the global within the local; recognizing futures in local roots; identifying territorial values; translating values into action).
Propose initiatives of civic engagement to challenge and overcome cultural stereotypes.
Assessment and verification activities (formative and summative)
Draw a mental map of the route followed.
Compare Via Morazzone and Via Paolo Sarpi and describe their differences.
Detect neighborhood changes using historical photographs.
Identify elements and markers of Chinese and Lombard cultures.
Apply the EaT method by completing a geolocated table.
Describe the soundscape and olfactory landscape or document architectural elements.
Situate the neighborhood within the broader urban context.</td>
</tr>
</table>

	These activities will allow us to evaluate the effectiveness of each delivery modality (Milan, Brescia, Piacenza) in consolidating the central functions of spatial intelligence.

The prototype phase still represents brainstorming, although the main ideas are converging, and maintains design flexibility: some solutions, contents and operational choices may still be modified depending on the final selection of technologies and apps. Decisions about hardware, platforms and multimedia tools will affect logistical and pedagogical aspects (e.g., group organization, level of immersion, assessment methods), so a refinement phase remains open and will conclude with the prototype validation meeting scheduled for September.

4.2.3 The Consolidation and Validation Sheet

When to use: the Consolidation & Validation Sheet (Tab. 29) is used during the third (and final) co-design workshop, a session specifically devoted to validating and tightening the ideas generated earlier in the cycle. The meeting follows a clear sequence: presentation and review of the full prior documentation (i.e., profiling sheet and prototyping sheet), a systematic line-by-line check to remove ambiguities and align stakeholders, targeted refinements based on new insights, and the definition of a detailed timeline for the MetaLab. In parallel, the template structures the testing plan (a small-scale run led by the instructor/ researchers to verify pedagogical or psychological effects of the MetaLab) and finishes with an explicit assignment of responsibilities and next steps.

Purpose: this template is designed to capture and finalize all elements needed to move a MetaLab from concept to practice it consolidates the date and micro-organization (e.g. timings) of the MetaLab, team roles, documents logistical needs, records the possible data-collection process that might go parallel to the MetaLab implementation and success criteria. In other words, it acts as a *deployment runbook*. By bringing all these connected elements into a single, actionable sheet, the template ensures that the prototype is coherent, testable and ready for smooth operationalization.

Tab. 29. The Consolidation and Validation Sheet.

		Location *Sede*		-
		Instructor *Docente*		-
		Course *Insegnamento*		-
		Number of students *Numero di studenti*		-
		MetaLab duration *Durata MetaLab*		-
		Data e orario MetaLab *MetaLab date and time*		-
		MetaLab mode (Immersive: exclusively with headsets; non-immersive: without headsets using only personal devices; Mixed: headsets and personal devices) *Modalità MetaLab (Immersiva: esclusivamente con visori; Non Immersiva: senza visori utilizzando esclusivamente dispositivi personali; Mista: visori e dispositivi personali)*		-
	MetaLab Information *Informazioni MetaLab*	**Any prerequisites for students** *Eventuali prerequisiti per gli studenti*		-
		Personal devices (for Non-Immersive and Mixed modes) *Dispositivi personali (per la modalità Non Immersiva e Mista)*		-
	Student information collection *Raccolta informazioni studenti*	**Accessibility** *Accessibilità*		-
		Materials preparation *Preparazione materiali*		-
General information *Informazioni generali*	**Adaptations for Inclusivity** *Adattamenti per l'Inclusività*	**In-class support** *Supporto in aula*		-
		Description *Descrizione*		-
		Main themes *Temi Principali*		-
		Metaversity project intro (duration: ~30 sec / ~1 min) *Intro Progetto Metaversity (durata: ~30 sec / ~1 min)*		-
	Introduction (20 min) *Introduzione (20 min)*	**Method of presenting the main themes** *Metodo di presentazione dei temi principali*		-
MetaLab structure *Struttura MetaLab*	**Experience** *Esperienza*	**Objective** *Obiettivo*		-

		Activities *Attività*		-
		Detailed instructions for students *Istruzioni dettagliate per gli studenti*		-
		Alternative options *Opzioni alternative*		-
	Discussion and Reflection (20 min) *Discussione e Riflessione (20 min)*	**Objective** *Obiettivo*		-
		Activities *Attività*		-
		Post-experience assessment (5–10 min) *Valutazione post-esperienza (5-10 min)*		-
Logistics, technical and human resources *Logistica, risorse tecniche e umane*	**Logistics** ***Logistica***	**Classroom** *Aula*		-
		Back-office room *Aula di back office*		-
		Didactic materials *Materiale didattico*		-
		VR equipment *Attrezzatura VR*		-
		Hygiene supplies *Materiale igienico*		-
		Other *Altro*		-
	Technical resources *Risorse tecniche*	**Software** *Software*		-
		Connection *Connessione*		-
		Backup *Backup*		-
		Software accessibility *Accessibilità software*		-
	Personnel *Personale*	**Immersive Learning Designer** *Immersive Learning Designer*		-
		Head of accessible experiences *Resp. Esperienze accessibili*		-

		Technical support – Software development *Assistenza Tecnica - Sviluppo Software*		-
		Classroom assistance *Assistenza d'aula*		-
		Headset management *Gestione caschi*		-
		Classroom booking *Prenotazione aula*		-
		Video-photographic documentation of the MetaLab *Documentazione video-fotografica del Metalab*		-
		Head of technical support *Resp. supporto tecnico*		-
		Evaluation method *Metodo di valutazione*		-
	Evaluation and Feedback *Valutazione e Feedback*	**Student feedback** *Feedback degli studenti*		-
		Post-lesson materials *Materiale post-lezione*		-
Follow-up and evaluation *Follow-up e valutazione*	**Follow-up** *Follow-up*	**Subsequent activities** *Attività successive*		-
		Concept *Concept*		-
		Theatre *Teatro*		-
		Knowledge garden *Giardino della conoscenza*		-
		Number of stops *Numero tappe*		-
		Order of stops *Ordine tappe*		-
		Virtual elements *Elementi virtuali*		-
		Holodeck *Holodeck*		-
		Third-party apps *App terze parti*		-
Virtual environment design *Design ambiente virtuale*	**Virtual environment design** *Design ambiente virtuale*	**Accessibility adaptations** *Adattamenti per l'accessibilità*		-

Link to the Geography example: in the *Virtual Tour of Milan's Chinatown* case, the Consolidation & Validation template of Professor Molinari's "Geografy with Laboratory" course (Tab. 30), was essential for turning brainstorming into an actionable runbook for the Geography MetaLab: it captured and formalized pedagogical choices (i.e., a single Chinatown journey delivered in three modalities), scheduled logistics (i.e., Milan immersive session held on Tue 6 May, 15:00–18:00, and remote session held on Thu 8 May, 9:30–12:30), and clarified scale (i.e., ≈ 20 students for the immersive Milan lab; ≈ 150 for the remote lab). It made explicit technical and material needs (i.e., ≈ 20 headsets with charging tower, sanitizing gel and hygiene masks, back-office room, and stable connectivity), the selection of the software for VR experience and a concrete Backup plan. It also helped in operationalizing the data collection and evaluation via pre-lesson Qualtrics surveys to census devices, VR familiarity and accessibility needs, plus a short post-lesson questionnaire for student feedback. The sheet also defined inclusive alternatives (i.e., non-VR participation options and alternate content versions), detailed the flow of the session (i.e., intro, immersive/semi-immersive[14], reflection and short post-experience assessment), and scheduled a rehearsal. Crucially, it assigned clear ownership for implementation tasks (e.g., SB as ILeD and headset lead, FC for accessible experiences, etc.) so responsibilities and next steps are traceable. By aggregating pedagogical aims, technical specs, personnel, assessment methods and outstanding risks in one place, the template enabled rapid coordination among stakeholders and prepared the prototype for final validation.

[14] The in-person class has not been conducted within the Metaversity project. Therefore, no details regarding this activity are provided in the table below.

Tab. 30. The Consolidatoin and Validation Sheet that was used for the co-design of Geography with Laboratory course.

		Location *Sede*	Milan (Immersive MetaLab) – Online (semi-immersive MetaLab)	-
		Instructor *Docente*	Paolo Molinari	-
		Course *Insegnamento*	Geography (with laboratory)	-
		Number of students *Numero di studenti*	Approx. 20 (Immersive MetaLab) – 150 (semi-immersive MetaLab)	-
		MetaLab duration *Durata MetaLab*	3:00–6:00 PM (Immersive MetaLab) – 9:30 AM–12:30 PM (semi-immersive MetaLab)	-
		Data e orario MetaLab *MetaLab date and time*	Tuesday, May 6 (Immersive MetaLab) - Thursday, May 8 (semi-immersive MetaLab)	-
		MetaLab mode (Immersive: exclusively with headsets; non-immersive: without headsets using only personal devices; Mixed: headsets and personal devices) *Modalità MetaLab (Immersiva: esclusivamente con visori; non-immersiva: senza visori utilizzando esclusivamente dispositivi personali; Mista: visori e dispositivi personali)*	Immersive || semi- immersive	-
	MetaLab Information *Informazioni MetaLab*	**Any prerequisites for students** *Eventuali prerequisiti per gli studenti*	None	-
		Personal devices (for Non-Immersive and Mixed modes) *Dispositivi personali (per la modalità Non Immersiva e Mista)*	Send a pre-lesson questionnaire (via Qualtrics) to collect data on: • Availability of smartphone, laptop • Familiarity with VR/AR technologies • Any additional information useful for scientific experimentation	-
	Student information collection *Raccolta informazioni studenti*	**Accessibility** *Accessibilità*	Send a pre-lesson questionnaire to collect data on: • Possible disabilities or sensory/motor limitations • Need for specific supports (e.g., subtitles, audio descriptions) • Potential VR-related motion sickness issues	-
		Materials preparation *Preparazione materiali*	• Alternative versions of content for students with limitations • Non-VR participation options for those who need them	-
General information *Informazioni generali*	**Adaptations for Inclusivity** *Adattamenti per l'Inclusività*	**In-class support** *Supporto in aula*	[Specify if in-class support for students with specific needs is required]	-
MetaLab structure		**Description**		-

Struttura MetaLab	**Introduction (20 min)** *Introduzione (20 min)*	*Descrizione*		
		Main themes *Temi Principali*		-
		Metaversity project intro (duration: ~30 sec / ~1 min) *Intro Progetto Metaversity (durata: ~30 sec / ~1 min)*	Can be presented in Spatial.io's theatre – CREATE a video trailer for all three proposed experiences	-
		Method of presenting the main themes *Metodo di presentazione dei temi principali*	PowerPoint + Video presentation seen on mirroring (Immersive MetaLab) and on personal devices (non-immersive).	-
	Experience *Esperienza*	**Objective** *Obiettivo*	• To integrate real and virtual naturalistic experiences, exploring the possibilities offered by different levels of immersion. • To create an educational experience that is engaging, inclusive and accessible to all students. • To study the effectiveness of different modes of delivery by comparing students' responses, verifying comprehension through specific questions, analyzing the achievement of learning objectives across different modes.	-
		Activities *Attività*	The experience focuses on a single route in the Chinatown district of Milan (Paolo Sarpi area), but is offered in three different modes: • **Milan students**: fully immersive experience using VR headsets • **Brescia students**: semi-immersive version of the route, using GIS tools such as Google Earth, Google Maps, and Google Street View for virtual navigation of the area • **Piacenza students**: traditional experience, with an in-person site visit* Despite the different delivery modes, the laboratory maintains the same content and activities for all groups, adapting them to the specificities of each exploration mode. * This activity has not been performed within the Metaversity project.	-
		Detailed instructions for students *Istruzioni dettagliate per gli studenti*	[Add a short guide on how to use the headsets and navigate in Spatial.io]	-
		Alternative options *Opzioni alternative*	Provide parallel activities for those who cannot use VR headsets (e.g., mirroring with a computer)	-
	Discussion and Reflection (20 min) *Discussione e Riflessione (20 min)*	**Objective** *Obiettivo*	Consolidate learning and collect feedback	-
		Activities *Attività*	General discussion, guided by the instructor	-
		Post-experience assessment (5–10 min) *Valutazione post-esperienza (5-10 min)*	Final evaluation via Qualtrics questionnaire + (i) draw a mental map of the route followed, (ii) compare Via Morazzone and Via Paolo Sarpi and describe their differences, (iii) detect neighborhood changes using	-

			historical photographs, (iv) identify elements and markers of Chinese and Lombard cultures, (v) apply the EaT method by completing a geolocated table, (vi) describe the soundscape and olfactory landscape or document architectural elements; (vii) situate the neighborhood within the broader urban context.	
Logistics, technical and human resources *Logistica, risorse tecniche e umane*	**Logistics** ***Logistica***	**Classroom** *Aula*	• Projector or large screen • Audio system • Stable internet connection (check WiFi network) • Seating arrangement [specify] • Wheelchair accessibility <u>To be booked</u>	-
		Back-office room *Aula di back office*	<u>To be booked</u>	-
		Didactic materials *Materiale didattico*		-
		VR equipment *Attrezzatura VR*	Approx. 20 headsets (install application on them) + hand sanitizer + 5 sets of batteries	-
		Hygiene supplies *Materiale igienico*	30 VR hygene masks	-
		Other *Altro*	Charging tower	-
	Technical resources *Risorse tecniche*	**Software** *Software*	Spatial.io, Wander application	-
		Connection *Connessione*	Check for internal connection Wicatt	-
		Backup *Backup*	Use Google Street View for the journey	-
		Software accessibility *Accessibilità software*	<u>To be verified</u>	-
	Personnel *Personale*	**Immersive Learning Designer** *Immersive Learning Designer*	SB	-
		Head of accessible experiences *Resp. Esperienze accessibili*	FC	-
		Technical support – Software development *Assistenza Tecnica - Sviluppo Software*	AB || LY	-
		Classroom assistance *Assistenza d'aula*	AU || CR	-

		Headset management *Gestione caschi*	SB	-
		Classroom booking *Prenotazione aula*	SB ‖ AG	-
		Video-photographic documentation of the MetaLab *Documentazione video-fotografica del Metalab*	<u>To be defined</u>	-
		Head of technical support *Resp. supporto tecnico*	FS	-
		Evaluation method *Metodo di valutazione*	Qualtrics survey pre and post	-
	Evaluation and Feedback *Valutazione e Feedback*	**Student feedback** *Feedback degli studenti*	Qualitative assessment during debriefing phase (general discussion after the MetaLab)	-
		Post-lesson materials *Materiale post-lezione*		-
Follow-up and evaluation *Follow-up e valutazione*	**Follow-up** *Follow-up*	**Subsequent activities** *Attività successive*		-
		Concept *Concept*	Metaversity video introduction – Experience	-
		Theatre *Teatro*	Metaversity video introduction on the theatre environment for both groups (Immersive ‖ semi-immersive) – Experience on Wander app (Immersive group) and on Google street view (Semi-immersive group)	-
		Knowledge garden *Giardino della conoscenza*	Not used	-
		Number of stops *Numero tappe*	14 (*see* below)	-
Virtual environment design *Design ambiente virtuale*	**Virtual environment design** *Design ambiente virtuale*	**Order of stops** *Ordine tappe*	**Proposed route (Chinatown: key stops and prompts)** 1. Zoom from Comune di Milano to Zone Sarpi: define Chinatown boundaries. 2. *To be evaluated:* map Via Canonica along the Sempione axis. 3. Piazza Morselli 3: *borgo dei Scigulat*, the farmhouse where the first Chinese residents were housed. 4. Via Canonica 39: Basso hairstyling (compared with historical photographs). 5. Continue along Via Canonica to Largo Medici; Via Canonica 54: Kathay supermarket.	-

			6. Via Morazzone 6: major commercial/import businesses. 7. Shops between Via Morazzone 6 and 8: chinese commercial activities. 8. Via Giordano Bruno 17: Chinese restaurant “Mare d’Oro”. 9. Via Giordano Bruno corner Via Rosmini: Bar Felice. 10. Via Rosmini to Via Giusti 15/A: “Giusti” primary school. 11. Via Giusti corner Via Verga: urban redevelopment project. 12. Via Nicolini to Via Paolo Sarpi: observe street life (e.g., presence of Chinese residents in Street View). 13. Via Paolo Sarpi 26: Chinese Cultural Centre. Use 3D Maps to inspect typical Milanese housing types (e.g., *casa di ringhiera*).	
		Virtual elements *Elementi virtuali*	Not used	-
		Holodeck *Holodeck*	Not used	-
		Third-party apps *App terze parti*	Wander – Google Street view	-
		Accessibility adaptations *Adattamenti per l'accessibilità*	• Alternative navigation options • Audio descriptions of visual elements	-

4.2.4 Guidelines for Toolkit

In sum, in the previous paragraph it has been illustrated how the *MetaLab Toolkit* for Co-Design functions as both a conceptual bridge and a pragmatic scaffolding tool, translating the Metaversity Project's theoretical foundations into actionable practices. Through the progressive sequence of templates (i.e., the Profiling Sheet, Prototyping Sheet, and Consolidation & Validation Sheet) the toolkit could enable instructors, designers, and developers to progressively refine XR learning experiences. The case study of Professor Molinari's "Geography with Laboratory" course demonstrated this iterative trajectory, moving from high-level pedagogical objectives to concrete XR pathways (i.e., immersive, semi-immersive XR learning experiences). By systematizing design decisions, foregrounding accessibility and inclusivity requirements, and aligning stakeholders around common goals, the toolkit reduces the cognitive and logistical burden of XR adoption while promoting reproducibility and comparability across contexts.

To use the templates effectively:

- Treat the templates as *living documents*, where incomplete sections in early workshops are expected and later revisited as design ideas consolidate.
- Emphasize *stakeholder collaboration*: co-design meetings should foster active reflection and negotiation with the ILeaD/ other team members guiding instructors from broad visions to actionable learning goals.
- Ensure that *accessibility considerations* are embedded from the start, by collecting data on students' devices, disabilities, and learning needs, so that inclusivity becomes integral rather than an afterthought.
- Adopt a *practical facilitation strategy*: schedule meetings with clear objectives (i.e., profiling, prototyping, validation), assign roles and responsibilities transparently, and document every decision for cumulative learning across implementations.

When applied in this way, the toolkit does not merely standardize XR design processes but creates a replicable pathway that enables universities to scale immersive learning while maintaining pedagogical integrity, inclusivity, and collaboration.

4.3 Recommendations for Scaling and Institutional Adoption

Scaling Extended Reality (XR) from isolated pilots to sustained institutional practice requires a conceptual shift, from device-centered experimentation to an integrated model encompassing governance, pedagogy, and infrastructure. Within this perspective, scalability is not primarily a function of the number of headsets deployed, but rather of the institution's capacity to align learning objectives, assessment methods, accessibility provisions, risk and privacy management, and the total cost of ownership within a coherent and evidence-informed strategy. A phased roadmap with explicit exit criteria could enable institutions to monitor progress, manage risks, and evaluate alignment with intended learning outcomes (Tab. 31).

Tab. 31. Summary of Recommendations for Scaling and Institutional Adoption

Phase	Objectives	Key Activities
Phase 1: Pilot (Exploration & Feasibility)	• Test XR in limited courses • Evaluate curriculum alignment • Identify infrastructure & accessibility needs	• Select early-adopter faculty and co-design XR modules • Deploy small-scale XR kits (10–20 headsets) • Collect data (usability, learning outcomes, accessibility) • Conduct risk & privacy assessments
Phase 2: Program (Integration & Standardization)	• Scale from single pilots to program-level adoption • Standardize co-design templates & accessibility guidelines • Establish shared XR services	• Integrate XR across multiple courses within a program • Launch faculty training (micro-credentials, workshops) • Build XR content repository & lending pools • Develop evaluation protocols tied to assessment
Phase 3: Platform (Institutionalization & Sustainability)	• Transition to institution-wide XR capability • Ensure interoperability, governance & sustainability • Embed XR into strategy & QA processes	• Deploy OpenXR-compliant platforms with web/desktop fallbacks • Integrate XR into LMS, catalogs, QA systems • Establish cross-unit governance (IT, library, disability services, legal/privacy) • Develop procurement frameworks with privacy & end-of-life guarantees • Build external partnerships for scale & cost sharing

Educational innovation driven by immersive technologies often emerges from bottom-up experimentation at the instructional level, yet its implementation frequently collides with top-down institutional and policy constraints. Research on systemic educational change has consistently shown that misalignment between pedagogical innovation and governance structures can significantly limit the scalability and long-term impact of technology-enhanced learning initiatives (Fullan, 2016; Cuban, 2018). In the case of XR, these tensions are amplified by issues related to interoperability, accreditation, and infrastructural dependency, which require coordination beyond individual courses or instructors. Recent studies suggest that innovation is more likely to be sustained when immersive technologies are framed as adaptable pedagogical infrastructures rather than disruptive replacements of existing curricula (Conole, 2014; Ehlers, 2020). Practical strategies proposed in the literature include modular integration, cross-institutional design frameworks, and the development of shared pedagogical languages that facilitate dialogue between educators, technical experts, and policy makers. Such approaches can help bridge the gap between experimental XR practices and policy-driven requirements for accountability, quality assurance, and standardization.

Sector analyses (e.g., EDUCAUSE, 2023) consistently emphasize that institutional-scale adoption is more likely when XR initiatives are explicitly linked to programme-level learning goals and assessment frameworks, rather than to technological novelty or hardware renewal cycles. Moreover, governance structures that define standards for procurement, safety, hygiene, and classroom integration appear critical for sustaining quality and equity. Institutional capacity building also depends on the development of shared services, such as equipment lending pools, content repositories, faculty training pathways, and communities of practice, as well as on the implementation of cross-unit workflows that connect IT services, instructional design, libraries, and disability support. Such measures foster standardization and reduce dependence on individual or ad-hoc pilot initiatives.

Evidence from the Jisc (2023/24) sector survey, based on 157 responses from 110 institutions across UK higher and further education, indicates that a large proportion of universities have progressed beyond the pilot phase, particularly in health, STEM, and arts disciplines. Reported benefits include enhanced situated and experiential learning, improved employability skills, and safer environments for practice, consistent with Bailenson's DICE framework (dangerous, impossible, counterproductive, expensive). However, persistent barriers remain, notably in terms of financial resourcing, staff competencies, and accessibility. These findings underscore the importance of adopting XR maturity models and toolkits to identify bottlenecks (e.g., staff time, accessibility retrofitting, network constraints) and to guide incremental, evidence-based improvements rather than fragmented expansion.

From a pedagogical standpoint, recent meta-analyses suggest that XR can support improvements in engagement and learning outcomes, although these effects are moderated by cognitive load, task–technology fit, and accessibility (Radianti et al., 2020; Yu & Xu, 2022). When tasks are poorly aligned with learning objectives or overly demanding, potential benefits may be neutralized, and some students, particularly those with motion sensitivity or limited device access, may be disadvantaged. For this reason, dual-mode delivery (immersive and non-immersive/web-based alternatives) should be considered a fundamental design principle, ensuring equitable participation and instructional continuity. Furthermore, formative evaluation embedded in courses, based on concise, theory-informed measures and performance-based tasks, can help instructors iteratively adapt learning designs to maintain balance between cognitive challenge, usability, and accessibility. Equally important is the systematic integration of accessibility and inclusion principles at the design stage. Frameworks such as Universal Design for Learning (UDL) can guide the development of multimodal XR experiences that include audio descriptions, seated modes, device-agnostic access, and pre-session screening for motion sensitivity. These strategies echo approaches adopted in the *Metaversity* initiative, where accessibility questionnaires were administered in advance to capture students' device availability and specific needs, thereby promoting inclusive participation.

From a technological and governance perspective, interoperability and vendor dependency should be treated as primary design constraints. The adoption of standards-based architecture (e.g., OpenXR runtime compatibility) reduces switching costs and enhances content portability across devices. Procurement frameworks should therefore mandate compliance with data protection regulations (e.g., GDPR), content exportability, web or desktop equivalents for essential learning activities, and a transparent end-of-life plan. The discontinuation of Google Expeditions in 2021 exemplified the fragility of proprietary, app-dependent deployments, whereas institutions that maintained web-based fallback options experienced minimal disruption. Empirical examples such as HoloAnatomy® at Case Western Reserve University and Dreamscape Learn at Arizona State University demonstrate that sustainable scaling is more likely when pedagogy, governance, and infrastructure evolve concurrently. In these cases, curriculum redesign, faculty development, and centralized support were implemented alongside platform strategies, resulting in consistent integration of XR into academic programs. By contrast, projects that focused narrowly on hardware acquisition lacked curricular alignment or accessibility protocols or failed to establish governance mechanisms tended to remain short-lived or fragmented.

It also should be noted that a further challenge concerns the rapid obsolescence of XR hardware and software, which poses significant difficulties for educational systems characterized by long development cycles and constrained resources. Studies on educational technology adoption have shown that short innovation cycles often undermine institutional investment and faculty engagement, particularly when tools become outdated before pedagogical models are fully consolidated (Weller, 2020; Selwyn et al., 2020). In the XR domain, this volatility complicates the development of time-resilient educational practices and raises concerns regarding cost-effectiveness and sustainability. Rather than pursuing technological stability, recent scholarship advocates for pedagogical abstraction and design portability as strategies to cope with rapid technological change (Koehler & Mishra, 2009; Beetham & Sharpe, 2019). By focusing on transferable learning designs, competencies, and experiential patterns rather than device-specific implementations, educational institutions may mitigate the risks associated with technological obsolescence while preserving the pedagogical value of immersive learning approaches.

The widespread reliance on proprietary XR platforms introduces complex challenges related to data governance and regulatory compliance, particularly with respect to privacy and data protection frameworks such as the General Data Protection Regulation (GDPR)[15]. As highlighted by scholars in critical data studies, contemporary educational technologies increasingly operate within opaque data ecosystems, in which the collection, processing, and circulation of personal data are structurally embedded within platform architectures and terms of service, often beyond the direct control of educational institutions (Kitchin, 2014; Tzimas &

[15] https://gdpr-info.eu/

Demetriadis, 2021). In XR contexts, these challenges are further intensified by the nature of the data involved, which may include biometric, behavioral, and spatial information that can be considered highly sensitive under data protection regulations. Moreover, XR platforms frequently function across transnational infrastructures, raising additional concerns related to data localization, cross-border data transfers, and the uneven application of regulatory standards between EU and non-EU jurisdictions.

From a regulatory perspective, the GDPR establishes strict principles regarding data minimization, purpose limitation, transparency, and informed consent, which can be difficult to fully operationalize within proprietary XR ecosystems that rely on persistent user accounts and continuous data exchange for core functionalities (Karunaratne, 2021). While fully open, interoperable, and GDPR-compliant XR infrastructures remain limited in practice, the literature emphasizes a set of pragmatic mitigation strategies aimed at reducing regulatory and ethical risks rather than eliminating them altogether. These include minimizing the collection of personal and biometric data, mediating user access through institutional accounts where feasible, increasing transparency in consent and data use practices, and embedding data protection considerations directly into instructional design and technology selection processes (Pardo & Siemens, 2014). Although such measures do not resolve the structural tension between proprietary platform logics and public regulatory frameworks, they contribute to more responsible, informed, and context-sensitive deployment of XR technologies in educational settings, particularly within higher education institutions operating under stringent data protection regime.

In conclusion, the sustainable institutionalization of XR in higher education appears more probable when technology is conceptualized as a strategic academic capability rather than as a transient innovation. Long-term success depends on systematic evaluation of learning effectiveness, inclusivity, and cost-efficiency, supported by maturity-guided services and standards-based infrastructures that remain resilient to staff turnover and market volatility. The overarching imperative is to scale with pedagogy and policy, ensuring that each immersive experience is complemented by an equitable non-immersive alternative, that procurement and governance frameworks embed principles of privacy, portability, and accessibility, and that course teams iteratively refine designs based on empirical evidence rather than technological enthusiasm.

To implement these recommendations, institutions might:

1. Establish an XR steering group including instructional designers and learning innovation representatives; adopt an institutional XR maturity toolkit to baseline current capability and set semester-by-semester targets.
2. Fund shared services (e.g., device pools, sanitation procedures, technical staffing) and create content repositories and communities of practice to support faculty engagement.
3. Adopt dual-mode delivery for XR activities (immersive and non-immersive/web versions) and codify accessibility using UDL checklists and pre-participation screenings.
4. Mandate open standards (OpenXR) and GDPR-compliant data processing in procurement, ensuring asset portability and long-term interoperability.
5. Embed formative evaluation within courses and disseminate results in open-access repositories to contribute to cumulative, reproducible practice.

The findings and methodological approach developed through the MetaLab framework provide an empirical foundation for understanding how immersive learning can evolve from localized experimentation to sustainable institutional practice. By conceptualizing XR as an experience-centered ecosystem, where cognitive, emotional, and motivational processes are systematically designed, observed, and evaluated, the MetaLab studies aimed at contributing to bridging the gap between small-scale pedagogical innovation and the structural requirements of university-wide implementation.

The framework's iterative and design-based orientation aligns closely with the phased model of XR maturity outlined above: both emphasize co-design with faculty, formative evaluation, and the continuous adjustment of learning environments based on evidence of cognitive load, affective engagement, and inclusivity.

In this sense, MetaLabs can be viewed as *microcosms of institutional transformation*, demonstrating how interdisciplinary collaboration, accessibility-by-design, and data-informed reflection can collectively sustain innovation beyond the pilot stage. The integration of these principles into academic governance, through shared evaluation protocols, open repositories, and cross-unit coordination, may enable universities to scale XR practices without compromising pedagogical quality or equity of access.

General Discussion and Conclusions

As stated at the beginning of the present work, the classroom has always reflected the evolution of its era, continually transforming in response to cultural, social, and technological change. From the chalkboard to overhead projectors, personal computers, and digital platforms, each technological shift has progressively reshaped how knowledge is conveyed and shared. Today, this transformation finds new expression in the emergence of Extended Reality (XR) learning environments, where the classroom can be visualized as a hybrid, three-dimensional space that blends physical and virtual elements. Students may interact simultaneously with tangible objects and digital overlays, collaborate through avatars or holographic projections, and manipulate 3D models of complex phenomena in real time. Within these immersive classrooms, learning unfolds not through passive observation but through embodied, multisensory, and collaborative exploration, marking a profound transition from the traditional lesson to an experiential, dynamic, and co-constructed educational reality.

The present doctoral dissertation tried to address some of the challenges that emerged with the introduction of XR technologies, by investigating how these can be responsibly and effectively integrated into higher education. To this end, it pursued four interconnected objectives: (i) to examine faculty and student expectations and concerns regarding XR adoption; (ii) to develop and validate a new instructional model for immersive learning, the MetaLab Model, that bridges pedagogical and technological domains; (iii) to empirically assess the model's impact on students' cognitive, affective, and motivational engagement; and (iv) to translate these findings into practical guidelines and co-design tools aimed at supporting the inclusive and scalable implementation of XR within real academic contexts.

The central hypothesis confirmed through empirical evidence is that the educational value of XR depends less on the degree of technological immersion and more on the *quality of experience* design, understood as the alignment between learning objectives, cognitive load management, emotional engagement, and accessibility principles. From this perspective, psychology emerges not merely as a supporting discipline, but as a foundational lens through which the human experience of technology-enhanced learning can be understood, designed, and evaluated.

Importantly, the research followed an iterative process inspired by the principles of *Design-Based Research* (DBR) and *Design Thinking* (DT), which ensured both methodological rigor and adaptability to real-world conditions. The combination of these two approaches enabled the generation of usable theoretical knowledge while continuously refining interventions in authentic educational contexts.

The research was structured around three interconnected phases, *Empathize, Prototype, and Test & Evaluation*, which together generated both analytical and practical contributions. In the *Empathize* phase (Chapter 1), two studies explored how faculty members and students perceive the opportunities and challenges associated with XR integration, examining adoption within the real constraints of higher education institutions. Building on these insights, the *Prototype* phase led to the conceptualization and formalization of a learner-centered instructional model, the MetaLab Model, and to the introduction of a new professional role, the Immersive Learning Designer (ILeaD), envisioned as a mediator between pedagogical, psychological, and technological domains described in Chapter 2. During the *Test & Evaluation* phase, the MetaLab model was empirically validated across multiple university contexts by assessing key dimensions of the learning experience such as usability, cognitive effort, epistemic emotions, absorption, and continuance intention. The outcome of this phase led to three sudies described in Chapter 3.

Finally, it translated these findings into an evidence-informed resource, the MetaLab Toolkit, which provides design guidelines, templates, and an institutional roadmap for the responsible scaling of immersive learning. Taken together, these outcomes constitute the original contribution of this doctoral research: the development of a theoretically grounded model for immersive learning, its empirical validation through multi-campus studies, and the operationalization of these insights into a transferable and evidence-based framework for higher education.

Across the different empirical studies conducted throughout this doctoral research, a coherent and complementary set of findings emerged, illuminating the psychological, pedagogical, and experiential mechanisms that underlie the effective integration of XR in higher education. The initial investigations conducted during the *Empathize* phase, involving both faculty members and students, revealed that direct experiential exposure combined with opportunities for reflection can transform initial skepticism into active engagement. Faculty workshops demonstrated that hands-on experimentation with immersive tools, when accompanied by structured dialogue and peer collaboration, fostered both awareness of XR’s pedagogical potential and a willingness to innovate. Participants highlighted the value of XR in simulating complex phenomena, fostering embodied understanding, and enhancing learner engagement, while simultaneously acknowledging institutional and human challenges such as accessibility, workload, and curricular integration.

These findings underscored that meaningful innovation in higher education requires not only technological readiness but also *participatory and reflective spaces* where professors can collaboratively explore new teaching paradigms.

Parallel to this, the longitudinal study with university students provided complementary insights into learners' expectations and post-adoption experiences, analyzed through the Extended Expectation-Confirmation Model (EECM). The results highlighted that experiential congruence, he degree to which actual use matches prior expectations, is a key determinant of satisfaction, perceived usefulness, and self-efficacy, all of which significantly predict students' willingness to continue using XR technologies. Contrary to traditional technology acceptance models, pre-adoption beliefs showed limited predictive power, suggesting that in the context of immersive learning, attitudes evolve primarily through embodied experience. When XR environments aligned with students' anticipations, they reported higher satisfaction, confidence, and motivation, whereas mismatches between expectations and actual experience tended to dampen enthusiasm. These outcomes point to the central importance of carefully designed experiential alignment, onboarding, and guided interaction in sustaining motivation and long-term engagement.

Building upon these insights, after the *Prototype* phase, aimed (as stated before) to the development of the MetaLab instructional model, the *Test & Evaluation* phases empirically validated the MetaLab instructional design model through multiple university implementations. The first study conducted within the course *"VR Techniques and Metaverse for Wellbeing"* offered one of the earliest examples of XR-based learning integrated directly into academic curricula. Two MetaLabs, focused respectively on embodiment and creativity, were co-designed with the instructor using social VR platforms, allowing students to engage in immersive collaborative tasks aimed at exploring the psychological dimensions of well-being. Results consistently indicated moderate-to-high levels of social presence, demonstrating that Virtual Reality Social (VRS) environments can effectively reproduce the immediacy and connection typical of in-person classrooms. Cognitive engagement was reflected in low extraneous cognitive load and high concentration, confirming that minimalist design and phased task segmentation successfully balanced immersion with cognitive manageability. Emotional data further showed a predominance of positive activating emotions (i.e., curiosity, enjoyment, and surprise) across both MetaLabs, highlighting that XR learning, when well-orchestrated, evokes engagement without overwhelming learners. However, individual variability in social presence and workload suggested the need for adaptive instructional strategies and preparatory sessions to mitigate computer anxiety and novelty effects, in line with multimedia learning principles such as pre-training.

Quantitative evidence from a larger cross-sectional study conducted with sixteen MetaLabs reinforced these findings, revealing that perceived usability is a central determinant of learning engagement and continuance intention in XR-based education. The high mean usability score (SUS = 80.5) indicated that XR technologies were perceived as highly intuitive and efficient, while cognitive and physical effort remained moderate, reflecting an optimal balance between immersion and control. Significant negative correlations between usability and perceived effort confirmed that clear affordances, intuitive navigation, and responsive feedback reduce cognitive strain and support fluid interaction. Regression analyses further demonstrated that usability alone accounted for 16% of the variance in continuance intention, emphasizing its motivational significance. These results align with the Cognitive-Affective Model of Immersive Learning (Makransky & Petersen, 2021), where usability functions as a bridge linking technological design and psychological experience by facilitating flow, curiosity, and self-efficacy.

The final investigation deepened the analysis by exploring the emotional and motivational dynamics underpinning XR learning, comparing immersive and non-immersive modalities in fourteen MetaLabs. Results demonstrated that positive activating emotions, were strong predictors of motivation to learn across both modalities. Although immersive environments elicited greater emotional arousal and attentional focus, they also increased cognitive effort and negative activating emotions such as frustration or confusion. In contrast, non-immersive settings produced comparable motivational outcomes with lower perceived strain, suggesting that the educational effectiveness of XR depends less on the degree of immersion and more on the quality of emotional design, narrative coherence, and cognitive pacing. Absorption remained high across all conditions, indicating that presence and engagement can be achieved through well-structured pedagogical design even without full sensory immersion. These findings confirm that emotional activation, rather than immersion per se, is the primary driver of motivation and learning persistence in XR-based education.

Taken together, the studies conducted throughout this dissertation converge on a consistent conclusion: effective and sustainable XR learning emerges from the alignment of usability, cognitive load, and emotional engagement within pedagogically grounded frameworks. When immersive environments are designed to balance stimulation with manageability, and when learners' expectations and emotions are intentionally supported, XR becomes a powerful medium for meaningful, inclusive, and transformative learning. The MetaLab framework thus provides empirical validation for a human-centered approach to immersive education, demonstrating that technological innovation achieves its full pedagogical potential only when it is guided by psychological insight, participatory design, and reflective practice.

While these results are robust within the scope of the research, they remain bound by the specific institutional ecosystem and sample sizes typical of doctoral inquiry. Technical heterogeneity and logistical constraints occasionally affected standardization, and future research should extend longitudinally to examine learning transfer, retention, and well-being over time.

While the present thesis adopts an overall positive stance toward the educational potential of XR, a critical perspective requires acknowledging a broader set of potential disadvantages beyond interface usability. Research in media psychology and learning sciences has raised concerns regarding attentional fragmentation, cognitive saturation, and the risk of prioritizing experiential intensity over conceptual understanding in highly immersive environments (Skulmowski & Rey, 2018). Additionally, immersive realism may reduce opportunities for abstraction and critical distance, particularly when learners are not supported by reflective scaffolding or debriefing activities (Fowler, 2015). Other scholars have highlighted ethical and psychosocial risks, including dependency on immersive stimulation, normalization of surveillance-based data practices, and unequal access to advanced technologies, which may reinforce existing educational disparities (Pea et al., 2023; Williamson, 2017). These considerations underscore the importance of positioning XR not as a neutral or inherently beneficial medium, but as a powerful educational intervention whose effects depend on intentional pedagogical design, ethical governance, and continuous evaluation.

Beyond the empirical findings, this work situates its contribution within the broader debate on the future of XR in higher education. Recent scholarship increasingly frames XR not as a discrete technology but as a human-centered ecosystem capable of connecting cognition, emotion, and embodiment in the learning process. Alnagrat and colleagues (2022) highlight how XR enables the creation of flexible, low-cost, and safe learning environments in which both teachers and students can experiment creatively, produce content autonomously, and transcend spatial and material constraints. These possibilities redefine the meaning of access and participation, shifting the focus from technological sophistication to pedagogical adaptability. Yet, as Taylor, tom Dieck, Jung, Cho, and Kwon (2024) argue in their review of XR and mental well-being, the expansion of immersive technologies, particularly in the context of Metaverse, requires a complementary ethical and psychological framework. They advocate a *positive psychology approach* that ensures cognitive engagement is balanced with emotional regulation, agency, and reflective depth. This resonates with the results of the present dissertation, which demonstrated that epistemic emotions and affective engagement are decisive in sustaining learning motivation across immersive and non-immersive settings.

Philosophical and design-oriented perspectives further enrich this reflection. Johnstone, McDonnell, and Williamson (2022) envision the advent of "ubiquitous XR," where individuals seamlessly traverse between physical and virtual realities, making immersive interfaces constant companions in everyday life. Their speculative work, through design fiction, reveals both the opportunities and ethical challenges of such a future: the potential for continuous learning embedded in daily experience, but also the risks associated with attention fragmentation, identity mediation, and cognitive overload. In this scenario, education assumes a crucial role as a space where the ethical and psychological foundations of human–technology interaction can be critically cultivated. The future of immersive learning, therefore, depends not only on technological innovation but on the development of emotional intelligence, ethical fluency, and metacognitive awareness in navigating these environments.

Insights from industry also inform this trajectory. Pitt (2020), examining XR adoption in the retail sector, underscores the importance of standardization, interoperability, and managerial flexibility for sustainable innovation. Translated into the educational sphere, these principles imply that universities must move beyond isolated pilot initiatives and develop open standards such as OpenXR (discussed in Chapter 4), shared governance mechanisms, and interdisciplinary expertise to ensure that immersive education is scalable, equitable, and institutionally coherent. Without such systemic alignment, XR risks remaining confined to experimental niches rather than evolving into a pedagogical infrastructure.

From a more pedagogical perspective, immersive learning environments do not mediate knowledge in isolation; they co-shape the qualities of the educational relationship, care, and ethical responsibility embedded in learning interactions (Biesta, 2013; Selwyn, 2019). According to Franco Cambi, pedagogical encounters and relational trust are core to education as an ethical practice (Cambi, 2018). This relational dimension becomes even more salient in XR, where affective and sensory engagement can intensify the learner's experience (Riva, 2008; Riva et al., 2021).

Complementary to this, Luigina Mortari highlights care and responsibility as foundational to educational practice (Mortari, 2015). In immersive contexts, ethical design includes consideration of emotional safety, accessibility, and cognitive load management (Bailenson, 2018; Madary & Metzinger, 2016). These factors not only influence engagement but also the learner's sense of agency and well-being. Empirical findings from the present thesis, such as variations in emotional engagement, perceived effort, and motivation, align with these ethical concerns, suggesting that XR implementation should be guided by pedagogies of care that foreground learner dignity and contextual responsiveness.

Taken together, these perspectives suggest that the most promising future for XR in higher education lies in its evolution as a human-centered extension of the learning experience. The challenge is not to increase immersion for its own sake, but to use immersive technologies to enhance *meaning-making*, *critical reflection*, and *emotional connection*. The integration of XR with artificial intelligence, learning analytics, and adaptive feedback systems holds great potential for personalization and cognitive support, but such developments must remain guided by ethical oversight that safeguard cognitive balance, emotional well-being, and fairness. The aim should not be to replace pedagogical intentionality with automation, but to augment it through adaptive and empathetic design.

In this perspective, psychology retains a central role as the discipline best equipped to study how humans perceive, feel, and learn within XR environments and to guide the responsible development of these technologies in educational contexts. By grounding the design of immersive learning in cognitive, affective, and motivational theory, psychology ensures that the integration of XR remains not only effective but also humanly sustainable.

In conclusion, this dissertation contributes to bridging the gap between the potential of XR technologies and their responsible institutional implementation, offering a coherent theoretical, empirical, and operational framework. It positions psychology as the core discipline for understanding and designing immersive learning experiences, advances the MetaLab Model as an evidence-based instructional and evaluative framework, and provides the MetaLab Toolkit as a practical instrument for scaling inclusive and sustainable XR adoption. By demonstrating that experiential quality, usability, and accessibility are stronger predictors of engagement and continuance than technological immersion alone, the research reframes XR as an experience-centered ecosystem guided by empathy, evidence, and equity. Within this framework, immersive technologies become not an end in themselves but a means of cultivating transformative, inclusive, and human-centered learning experiences, a pathway toward a higher education system that is technologically advanced yet profoundly human in its design, purpose, and impact.

Appendix I

	Pre-adoption variables Original item *IVR Italian-adapted item*	**Source**
	Performance Expectancy	
1	I find the metaverse educational platform to be useful for my study purposes. *Trovo che la realtà virtuale immersiva sarebbe utile per i miei scopi di studio.*	Teng et al. (2022)
2	Using the metaverse educational platform makes it easier for me to achieve my study goals. *L'utilizzo della realtà virtuale immersiva faciliterebbe il raggiungimento dei miei obiettivi di studio*	
3	Using the metaverse educational platform improves my learning efficiency. *L'utilizzo della realtà virtuale immersiva migliorerebbe la mia efficacia nell'apprendimento*	
	Effort Expectancy	

1	My interaction with the metaverse educational platform is clear and understandable. *La mia interazione con la realtà virtuale immersiva sarebbe chiara e comprensibile*	Teng et al. (2022)
2	I think the metaverse educational platform is easy to use. *Penso che le realtà virtuale immersiva sarebbe facile da usare*	
3	Learning to use the metaverse educational platform is easy for me. *Imparare ad usare la realtà virtuale immersiva sarebbe facile per me*	
	Post-adoption variables Original item *IVR Italian-adapted item*	**Source**
	Confirmation	
1	My experience with Web-based learning was better than what I expected. *La mia esperienza di apprendimento con la realtà virtuale immersiva è stata migliore di quanto mi aspettassi*	Li et al. (2022)
2	The knowledge level provided by Web-based learning was more abundant than what I expected. *Il livello di conoscenze fornito dalla realtà virtuale immersiva è stato maggiore di quanto mi aspettassi*	
3	Learning by using Web system was confirmed with what I expected. *L'esperienza di apprendimento con la realtà virtuale immersiva ha confermato le mie aspettative*	
	Post-adoption Perceived Usefulness	
1	Using web-based learning would improve my productivity in learning. *L'utilizzo della realtà virtuale immersiva migliorerebbe la mia produttività nell'apprendimento*	Li et al. (2022)
2	Using web-based learning would improve my academic performance. *L'utilizzo della realtà virtuale immersiva migliorerebbe il mio rendimento scolastico*	
3	I find the web-based learning is useful for me. *Penso che la realtà virtuale per l'apprendimento mi sia utile*	
	Satisfaction	
1	My overall experience of the M-wallet is satisfying. *La mia esperienza di apprendimento con la realtà virtuale immersiva è stata soddisfacente*	Gupta et al. (2020)
2	My overall experience of the M-wallet is pleasant. *La mia esperienza di apprendimento con la realtà virtuale immersiva è stata piacevole*	
3	My overall experience of the M-wallet is delightful. *La mia esperienza di apprendimento con la realtà virtuale immersiva è stata gradevole*	
	Self-efficacy	
1	I have the capability to use this M-wallet for making payments. *Ho le capacità per usare la realtà virtuale immersiva a scopo educativo*	Gupta et al. (2020)
2	I have the confidence to use this M-wallet for making payments. *Sono sicuro di me quando uso la realtà virtual immersive per l'apprendimento*	
3	I feel comfortable paying through this M-wallet. *Mi sento tranquillo/a nell'apprendere usando la realtà virtuale immersiva*	
	Continuance intention	
1	I intend to continue using web-based learning in the future. *Ho intenzione di continuare a usare la realtà virtuale per l'apprendimento in futuro*	Li et al. (2022)
2	I will continue using web-based learning as much as possible in the future.	

	Continuerò a usare la realtà virtuale immersiva per l'apprendimento quanto più possibile nel futuro	
3	I will continue using Web-based learning in the future. *Continuerò a usare la realtà virtuale immersiva per l'apprendimento in futuro*	

Appendix II

Student's Kit

Pre – Test

	English item *Original Italian item*
	Demographic Data
1	**Anonymization code** Please generate an alphanumeric code following this rule: first two letters of your first name, first two letters of your last name, day and month of birth. Use lowercase letters. Example: Mario Rossi 14/08/1957 = maro1408 ***Codice di anonimizzazione*** *Per favore, genera un codice alfanumerico seguendo la regola: prime due lettere del nome, prime due lettere del cognome, giorno e mese di nascita. Usa le lettere minuscole.* *Esempio: Mario Rossi 14/08/1957 = maro1408*
2	**Age** Please indicate your age in numbers (e.g., 23) ***Età*** *Per favore, indica la tua età in numeri (es. 23)*
3	**Gender** Please indicate your sex: o Female (1) o Male (2) o Prefer not to say (3) ***Genere*** *Per favore, indica il tuo sesso:* *o Femmina (1)* *o Maschio (2)* *o Preferisco non dirlo (3)*
4	**Field of study** Please indicate your field of study: o Area 01 - Mathematical and Computer Sciences (1) o Area 02 - Physical Sciences (2) o Area 03 - Chemical Sciences (3) o Area 04 - Earth Sciences (4) o Area 05 - Biological Sciences (5) o Area 07 - Agricultural and Veterinary Sciences (6) o Area 08 - Civil Engineering and Architecture (7) o Area 09 - Industrial and Information Engineering (8) o Area 10 - Classical, Philological-Literary and Art-Historical Sciences (9)

	o Area 11 - Historical, Philosophical, Pedagogical and Psychological Sciences (10) o Area 12 - Legal Sciences (11) o Area 13 - Economic and Statistical Sciences (12) o Area 14 - Political and Social Sciences (13) ***Campo di studi*** *Per favore, indica il tuo campo di studi:* *o Area 01 - Scienze matematiche e informatiche (1)* *o Area 02 - Scienze fisiche (2)* *o Area 03 - Scienze chimiche (3)* *o Area 04 - Scienze della terra (4)* *o Area 05 - Scienze biologiche (5)* *o Area 07 - Scienze agrarie e veterinarie (6)* *o Area 08 - Ingegneria civile e architettura (7)* *o Area 09 - Ingegneria industriale e dell'informazione (8)* *o Area 10 - Scienze dell'antichità, filologico-letterarie e storico-artistiche (9)* *o Area 11 - Scienze storiche, filosofiche, pedagogiche e psicologiche (10)* *o Area 12 - Scienze giuridiche (11)* *o Area 13 - Scienze economiche e statistiche (12)* *o Area 14 - Scienze politiche e sociali (13)*
5	**Year of study** Please indicate the year of study you are currently attending: o 1st year Bachelor / 1st year Single-Cycle Master (1) o 2nd year Bachelor / 2nd year Single-Cycle Master (2) o 3rd year Bachelor / 3rd year Single-Cycle Master (3) o 1st year Master / 4th year Single-Cycle Master (4) o 2nd year Master / 5th year Single-Cycle Master (5) o 6th year Single-Cycle Master (6) ***Anno di studi*** *Per favore, indica l'anno di corso che stai frequentando:* *o Primo anno Laurea Triennale / primo anno Laurea Magistrale a Ciclo Unico (1)* *o Secondo anno Laurea Triennale / secondo anno Laurea Magistrale a Ciclo Unico (2)* *o Terzo anno Laurea Triennale / terzo anno Laurea Magistrale a Ciclo Unico (3)* *o Primo anno Laurea Magistrale / quarto anno Laurea Magistrale a Ciclo Unico (4)* *o Secondo anno Laurea Magistrale / quindi anno Laurea Magistrale a Ciclo Unico (5)* *o Sesto anno Laurea Magistrale a Ciclo Unico (6)*
	Accessibility and Inclusivity
	During MetaLabs various tools and technologies will be used, including virtual reality. This may be experienced non-immersively (e.g., via desktop with mouse and keyboard or mobile) and/or immersively (e.g., via VR headset and controllers). To ensure a safe and inclusive learning experience, please answer the following questions. Your responses will help us adapt the experience to your needs. Information will be handled confidentially and used only for organizational purposes. You may stop the experience at any time and contact instructors or staff for assistance during the MetaLab. *Durante i MetaLab verranno utilizzate diverse strumenti e tecnologie, tra cui la realtà virtuale. Questa potrà essere utilizzata in modalità non immersiva (per esempio, tramite desktop, con il supporto di mouse e tastiera, oppure tramite mobile) e/o in modalità immersiva (per esempio, tramite visore di realtà virtuale e controller). Per garantire un'esperienza di apprendimento sicura e inclusiva, ti invitiamo a rispondere alle seguenti domande. Le tue risposte ci aiuteranno a adattare l'esperienza alle tue esigenze. Le informazioni saranno trattate in modo confidenziale e utilizzate solo per fini organizzativi. In ogni caso, ricorda che potrai interrompere l'esperienza in qualsiasi momento e che per tutta la durata del MetaLab potrai rivolgerti ai docenti e allo staff per qualsiasi difficoltà o chiarimento.*

1	Do you have **sensory limitations** (visual, auditory) that you think could prevent or limit your experience in virtual reality? o Yes (1) o No (2) If yes, can you briefly describe them? *Hai **limitazioni sensoriali** (visive, uditive) che ritieni possano limitare o non consentirti una esperienza in realtà virtuale?* *o Si (1)* *o No (2)* *Se si, puoi descriverle brevemente?*
2	Do you have **physical difficulties** that may make the use of virtual reality technologies uncomfortable? e.g., labyrinthitis; motor difficulties; neck, shoulder or back problems, etc. o Yes (1) o No (2) If yes, please indicate which ones: *Hai **difficoltà fisiche** che ritieni possono renderti poco agevole l'uso di tecnologie di realtà virtuale? Ad es: labirintite; difficoltà motorie; problemi al collo, spalle, schiena; ecc.* *o Si (1)* *o No (2)* *Se si, puoi indicare quali?*
3	Do you have **psychological or psychiatric conditions** that you think might be affected by a virtual reality experience (e.g., anxiety, claustrophobia, panic, other)? o Yes (1) o No (2) If yes, please specify which: *Hai **disturbi di tipo psicologico o psichiatrico** che ritieni potrebbero essere influenzati da un'esperienza in realtà virtuale (es. ansia, claustrofobia, panico, altro)?* *o Si (1)* *o No (2)* *Se si, specifica quali per favore:*
4	Are you currently experiencing **emotional conditions** that you think could be influenced by a virtual reality experience? o Yes (1) o No (2) If yes, please specify which: *Stai attualmente vivendo **condizioni emotive** che ritieni potrebbero essere influenzate da un'esperienza in realtà virtuale?* *o Si (1)* *o No (2)* *Se si, specifica quali*

5	Do you have **cognitive or learning difficulties** (e.g., specific learning disorders) that you think could make a VR experience difficult or unpleasant? o Yes (1) o No (2) If yes, please specify which: *Hai* ***difficoltà cognitive o di apprendimento*** *(DSA) che ritieni possano renderti difficile/sgradevole una esperienza in realtà virtuale?* *o Si (1)* *o No (2)* *Se sì, specifica quali per favore:*
6	Are there **cultural, religious or personal aspects** we should consider for making the VR experience more comfortable for you? o Yes (1) o No (2) If yes, can you provide further details? *Ci sono* ***aspetti culturali, religiosi o personali*** *che dovremmo considerare per rendere l'esperienza in realtà virtuale più confortevole per te?* *o Si (1)* *o No (2)* *Se sì, puoi fornirci maggiori dettagli?*
7	Do you require **specific adaptations** or supports to participate in VR experiences? o Yes (1) o No (2) If yes, please specify which: *Hai necessità* ***di adattamenti*** *o supporti specifici per partecipare a esperienze in realtà virtuale?* *o Si (1)* *o No (2)* *Se si, per favore specifica quali:*
8	Is there anything else you would like to share to help us make the experience safer and more enjoyable for you? If not, leave the box empty and proceed. *C'è qualcos'altro che vorresti condividere per aiutarci a rendere l'esperienza più sicura e piacevole per te? Se no, lascia la casella vuota e procedi.*
	Past experience with non-immersive virtual reality
	We are interested in your past experience with non-immersive virtual reality tools and technologies (e.g., desktop). Please respond using the following scale: 1 = never, 2 = rarely (1–2 times), 3 = sometimes (a few times), 4 = often, 5 = daily. *Siamo interessati a conoscere la tua esperienza passata con strumenti e tecnologie di realtà virtuale non immersiva (es. desktop). Per favore, rispondi alle seguenti domande utilizzando la seguente scala: 1 = mai (non li ho mai utilizzati), 2 = raramente (li ho utilizzati una o due volte), 3 = qualche volta (li utilizzato più volte), 4 = spesso (lo utilizzo spesso), 5 = quotidianamente (li utilizzo tutti quasi tutti i giorni).*
1	How often do you use non-immersive virtual reality tools (e.g., desktop)?

	Quanto spesso usi strumenti di realtà virtuale non immersiva (es. desktop)?
2	How often do you use non-immersive VR (e.g., desktop) in educational contexts? *Quanto spesso usi la realtà virtuale non immersiva (es. desktop) in contesti educativi?*
3	How often do you use social VR platforms (e.g., Spatial, Engage VR) in non-immersive mode (e.g., desktop)? *Quanto spesso usi piattaforma di realtà virtuale sociale (es. Spatial, Engage VR) in modalità non immersiva (es. desktop)?*
	Past experience with immersive virtual reality
	We are interested in your past experience with immersive virtual reality tools and technologies (e.g., headsets). Please respond using the same 1–5 scale as above. *Siamo interessati a conoscere la tua esperienza passata con strumenti e tecnologie di realtà virtuale immersiva (es. visori). Per favore, rispondi alle seguenti domande utilizzando la seguente scala: 1 = mai (non li ho mai utilizzati), 2 = raramente (li ho utilizzati una o due volte), 3 = qualche volta (li utilizzato più volte), 4 = spesso (lo utilizzo spesso), 5 = quotidianamente (li utilizzo tutti quasi tutti i giorni).*
1	How often do you use immersive VR tools (e.g., headsets)? *Quanto spesso usi strumenti di realtà virtuale immersiva (es. visori)?*
2	How often do you use immersive VR (e.g., headsets) in educational contexts? *Quanto spesso usi la realtà virtuale immersiva (es. visori) in contesti educativi?*
3	How often do you use social VR platforms (e.g., Spatial, Engage VR) in immersive mode (e.g., headsets)? *Quanto spesso uso piattaforme di realtà virtuale sociale (es. Spatial, Engage VR) in modalità immersiva (es. visori)?*
	Opinions about the MetaLab
	We are interested in your views regarding the MetaLab that will be part of your learning pathway. There are no right or wrong answers. Please indicate how much you agree with each statement using the following scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. *Siamo interessati a sapere cosa ne pensi rispetto al MetaLab che verrà inserito nel tuo percorso di apprendimento. Non ci sono risposte giuste o sbagliate. Per favore indica quanto sei d'accordo con ciascuna delle seguenti affermazioni utilizzando la seguente scala: 1 = fortemente in disaccordo, 2 = in disaccordo, 3 = neutro, 4 = d'accordo, 5 = fortemente d'accordo.*
1	I think the MetaLab will be useful for my study purposes. *Penso che il MetaLab sarà utile per i miei scopi di studio*
2	The MetaLab will facilitate achievement of my study goals. *Il MeteLab faciliterà il raggiungimento dei miei obiettivi di studio*
3	The MetaLab will improve my learning effectiveness. *Il MetaLab migliorerà la mia efficacia nell'apprendimento*
4	My interaction with the tools and technologies used in the MetaLab will be clear and understandable. *La mia interazione con gli strumenti e le tecnologie che verranno utilizzati nel MetLab sarà chiara e comprensibile*
5	I believe the tools and technologies used in the MetaLab will be easy to use. *Penso che gli strumenti e le tecnologie che verranno utilizzati nel MetaLab saranno facili da usare*
6	Learning to use the tools and technologies in the MetaLab will be easy for me. *Imparare a usare gli strumenti e le tecnologie che verranno utilizzati nel MetaLab sarà facile per me*

Post – Test

	English item *Original Italian item*

	Demographic Data
1	**Anonymization code** Please generate an alphanumeric code following this rule: first two letters of your first name, first two letters of your last name, day and month of birth. Use lowercase letters. Example: Mario Rossi 14/08/1957 = maro1408 ***Codice di anonimizzazione*** *Per favore, genera un codice alfanumerico seguendo la regola: prime due lettere del nome, prime due lettere del cognome, giorno e mese di nascita. Usa le lettere minuscole.* *Esempio: Mario Rossi 14/08/1957 = maro1408*
	Emotions
1	We are interested in how you felt during the MetaLab. There are no right or wrong answers. Please use the following scale to indicate how you felt for each adjective listed: 1 = Not at all, 2 = Very little, 3 = Moderately, 4 = A lot, 5 = Very much *Siamo interessati a come ti sei sentito/a durante il MetaLab. Non ci sono risposte giuste o sbagliate. Utilizza la seguente scala per indicare come ti sei sentito/a rispetto a ciascun aggettivo elencato:1= Per niente, 2= Molto poco, 3= Moderatamente, 4= Molto, 5= Moltissimo*
1	Surprised *Sorpreso/a*
2	Astonished *Stupito/a*
3	Amazed / Stupefied *Stupefatto/a*
4	Curious *Curioso/a*
5	Interested *Interessato/a*
6	Inquisitive (e.g., eager to ask questions, investigate) *Interrogativo/a (es., desideroso di fare domande, indagare)*
7	Happy *Felice*
8	Excited *Eccitato/a*
9	Joyful *Gioioso/a*
10	Confused *Confuso/a*
11	Disoriented *Disorientato/a*
12	Perplexed *Perplesso/a*
13	Anxious *Ansioso/a*
14	Worried *Preoccupato/a*
15	Nervous *Nervoso/a*
16	Frustrated *Frustrato/a*
17	Irritated

	Irritato/a
18	Unsatisfied *Insoddisfatto/a*
19	Bored *Annoiato/a*
20	Listless / Unenergetic *Spento/a*
21	Tedious / Weary *Tediato/a*
	Absorption
	We are interested in your experience during the MetaLab. There are no right or wrong answers. Please indicate how much you agree with each of the following statements using the scale: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree. *Siamo interessati alla tua esperienza durante il MetaLab. Non ci sono risposte giuste o sbagliate. Per favore indica quanto sei d'accordo con ciascuna delle seguenti affermazioni utilizzando la seguente scala: 1 = fortemente in disaccordo, 2 = in disaccordo, 3 = neutro, 4 = d'accordo e 5 = fortemente d'accordo.*
1	I was absorbed in the activity performed during the MetaLab *Ero assorto/a nell'attività svolta durante il MetaLab*
2	I was highly focused on the activity performed during the MetaLab *Ero molto concentrato/a sull'attività svolta durante il MetaLab*
3	All my attention was directed to the activity performed during the MetaLab *Tutta la mia attenzione era rivolta all'attività svolta durante il MetaLab*
	Motivation
	We are interested in your experience during the MetaLab. There are no right or wrong answers. Please indicate how much you agree with each of the following statements using the scale: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree. *Siamo interessati alla tua esperienza durante il MetaLab. Non ci sono risposte giuste o sbagliate. Per favore indica quanto sei d'accordo con ciascuna delle seguenti affermazioni utilizzando la seguente scala: 1 = fortemente in disaccordo, 2 = in disaccordo, 3 = neutro, 4 = d'accordo e 5 = fortemente d'accordo.*
1	The MetaLab made learning this subject more stimulating *Il MetaLab ha reso l'apprendimento di questa materia piu' stimolante*
2	The MetaLab made me curious about this subject *Il MetaLab mi ha incuriosito/a rispetto a questa materia*
3	I feel more motivated to learn this subject after participating in the MetaLab *Mi sento piu' motivato/a ad apprendere questa materia dopo aver partecipato al MetaLab*
4	Participating in the MetaLab increased my interest in studying this subject further *Partecipare al MetaLab ha aumentato il mio interesse per l'approfondimento di questa materia*
	Post EECM
	We are interested in your opinions about using MetaLabs in your learning pathway. There are no right or wrong answers. Please indicate how much you agree with each statement using the scale: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree. *Siamo interessati alle tue opinioni rispetto all'uso dei METALAB nel tuo percorso di apprendimento. Non ci sono risposte giuste o sbagliate. Per favore indica quanto sei d'accordo con ciascuna delle seguenti affermazioni utilizzando la seguente scala: 1 = fortemente in disaccordo, 2 = in disaccordo, 3 = neutro, 4 = d'accordo e 5 = fortemente d'accordo.*

1	My learning experience with the MetaLab was better than I expected *La mia esperienza di apprendimento con il MetaLab è stata migliore di quanto mi aspettassi*
2	The level of knowledge provided by the MetaLab was greater than I expected *Il livello di conoscenze fornito dal MetaLab è stato maggiore di quanto mi aspettassi.*
3	The MetaLab learning experience matched my expectations *L'esperienza di apprendimento con il MetaLab ha confermato le mie aspettative*
4	MetaLabs would improve my productivity in learning *I MetaLab migliorerebbero la mia produttività nell'apprendimento*
5	MetaLabs would improve my academic performance *I MetaLab migliorerebbero il mio rendimento scolastico*
6	I think MetaLabs are useful for learning *Penso che i MetaLab per l'apprendimento mi siano utili*
7	My MetaLab learning experience was satisfying *La mia esperienza di apprendimento con il MetaLab è stata soddisfacente*
8	My MetaLab learning experience was enjoyable *La mia esperienza di apprendimento con il MetaLab è stata piacevole*
9	My MetaLab learning experience was pleasant *La mia esperienza di apprendimento con il MetaLab è stata gradevole*
10	I have the skills to take part in MetaLabs for educational purposes *Ho le capacità per seguire i MetaLab a scopo educativo*
11	I feel confident when following a MetaLab for learning *Sono sicuro di me quando nel seguire un MetaLab per l'apprendimento*
12	I feel comfortable learning through MetaLabs *Mi sento tranquillo/a nell'apprendere tramite i MetaLab*
13	I intend to use MetaLabs for learning in the future *Ho intenzione sfruttare i MetaLab per l'apprendimento in futuro*
14	I will continue to use MetaLabs for learning as much as possible in the future *Continuerò a seguire i MetaLab per l'apprendimento quanto più possibile nel futuro*
15	I will continue to follow MetaLabs for learning in the future *Continuerò a seguire i MetaLab per l'apprendimento in futuro*
	Mental Effort
	We are interested in how you felt during the MetaLab. There are no right or wrong answers. Please indicate for each of the following statements how much effort the MetaLab activity required: 1 = Not at all, 2 = A little, 3 = Moderate, 4 = A lot, 5 = Very much. *Siamo interessati a sapere come ti sei sentito/a durante il MetaLab. Non ci sono risposte giuste o sbagliate.* *Per favore indica quanto per ciascuna delle seguenti affermazioni quanto sforzo ti ha richiesto l'attività svolta durante il METALAB: 1 = per niente, 2 = poco, 3 = moderato, 4 = molto e 5 = moltissimo.*
1	How much mental effort did complete the MetaLab require? *Quanto sforzo mentale ha richiesto lo svolgimento del MetaLab?*
2	How much physical effort did complete the MetaLab require? *Quanto sforzo fisico ha richiesto lo svolgimento del MetaLab?*
3	How much energy (mental and physical) did you need to invest to complete the MetaLab? *Quanta energia (mentale e fisica) hai dovuto impegnare per completare il MetaLab?*
	Perceived Learning
	We are interested in your opinions about using MetaLabs in your learning pathway. There are no right or wrong answers. Please indicate how much you agree with each statement using the scale: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree. *Siamo interessati alle tue opinioni rispetto all'uso dei MetaLab nel tuo percorso di apprendimento. Non ci sono risposte giuste o sbagliate. Per favore indica quanto sei d'accordo con ciascuna delle seguenti*

	affermazioni utilizzando la seguente scala: 1 = fortemente in disaccordo, 2 = in disaccordo, 3 = neutro, 4 = d'accordo e 5 = fortemente d'accordo.
1	I learned a lot about the subject covered during the MetaLab *Ho imparato molto sull'argomento trattato durante il MetaLab*
2	I gained a good understanding of the basic concepts of the subject covered during the MetaLab *Ho acquisito una buona comprensione dei concetti di base dell'argomento trattato durante il MetaLab*
3	I identified the main topics of the subject covered during the MetaLab *Ho identificato le tematiche principali dell'argomento trattato durante il MetaLab*
	Usability
	We are interested in your opinions about the tools and technologies used during the MetaLab (e.g., immersive VR headsets or desktop applications). There are no right or wrong answers. Please indicate how much you agree with each statement using the scale: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree. *Siamo interessati alle tue opinioni rispetto all'uso degli strumenti e delle tecnologie impiegate durante il MetaLab. Per strumenti e tecnologie si intende, per esempio: tecnologie VR immersive (es. visori) oppure tecnologie non immersive (es. applicazioni via desktop). Non ci sono risposte giuste o sbagliate. Per favore indica quanto sei d'accordo con ciascuna delle seguenti affermazioni utilizzando la seguente scala: 1 = fortemente in disaccordo, 2 = in disaccordo, 3 = neutro, 4 = d'accordo e 5 = fortemente d'accordo.*
1	I think I would like to use frequently the tools and technologies used during the MetaLab *Penso che mi piacerebbe utilizzare frequentemente gli strumenti e le tecnologie utilizzati durante il MetaLab*
2	I found the tools and technologies used during the MetaLab unnecessarily complex *Ho trovato gli strumenti e le tecnologie utilizzati durante il MetaLab complessi senza che ce ne fosse bisogno*
3	I found the tools and technologies used during the MetaLab easy to use *Ho trovato gli strumenti e le tecnologie utilizzati durante il MetaLab facili da usare*
4	I think I would need the support of someone already able to use the tools and technologies used during the MetaLab *Penso che avrei bisogno del supporto di una persona già in grado di usare gli strumenti e le tecnologie utilizzati durante il MetaLab*
5	I found the various tools and technologies used during the MetaLab well integrated *Ho trovato i vari strumenti e tecnologie utilizzati durante il MetaLab bene integrati*
6	I found inconsistencies between the various tools and technologies used during the MetaLab *Ho trovato incoerenze tra i vari strumenti e tecnologie utilizzati durante il MetaLab*
7	I think most people could quickly learn to use the tools and technologies used during the MetaLab *Penso che la maggior parte delle persone potrebbe imparare velocemente a usare gli strumenti e le tecnologie utilizzati durante il MetaLab*
8	I found the tools and technologies used during the MetaLab complicated to use *Ho trovate gli strumenti e le tecnologie utilizzati durante il MetaLab complicati da usare*
9	I felt very comfortable using the tools and technologies during the MetaLab *Mi sentivo molto a mio agio a utilizzare gli strumenti e le tecnologie utilizzati durante il MetaLab*
10	I needed to learn many things before being able to use the tools and technologies used during the MetaLab *Ho avuo bisogno di imaprare molte cose prima di poter utilizzare gli strumenti e le tecnologie utilizzati durante il MetaLab*
	Presence
	We are interested in how you felt during the MetaLab. There are no right or wrong answers. Please indicate how much you agree with the following statement using the scale: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

	Siamo interessati a sapere come ti sei sentito/a durante il METALAB. Non ci sono risposte giuste o sbagliate. Per favore indica quanto sforzo mentale ti ha richiesto lo svolgimento di questa attività: 1 = fortemente in disaccordo, 2 = in disaccordo, 3 = neutro/a, 4 = d'accordo e 5 = fortemente d'accordo.
1	I felt present in the virtual environment, as if I were really there *Mi sono sentito/a presente nell'ambiente virtuale, come se foste davvero li*

References

- Abeywardena, I. S. (2023). OXREF: open XR for education framework. *International Review of Research in Open and Distributed Learning*, *24*(3), 185-206.

- Abrahams, D. A. (2010). Technology adoption in higher education: A framework for identifying and prioritising issues and barriers to adoption of instructional technology. *Journal of Applied Research in Higher Education*, *2*(2), 34-49.
- Adams, D., Simpson, K., Davies, L., Campbell, C., & Macdonald, L. (2019). Online learning for university students on the autism spectrum: A systematic review and questionnaire study. *Australasian Journal of Educational Technology*, *35*(6), 111-131.
- Ainscow, M. (2005). Developing inclusive education systems: what are the levers for change?. *Journal of educational change*, *6*(2), 109-124.
- Al-Adwan, A. S., Li, N., Al-Adwan, A., Abbasi, G. A., Albelbisi, N. A., & Habibi, A. (2023). Extending the technology acceptance model (TAM) to Predict University Students' intentions to use metaverse-based learning platforms. *Education and Information Technologies*, *28*(11), 15381-15413.
- Aliyu, F., Talib, C. A., Aliyu, H., Mani, B. U., Sook, K. M., & Loon, S. C. (2020). A Preliminary Study for Designing and Developing Augmented Reality-Based Module for Teaching Chemical Bonding in Nigerian Secondary Schools. *Solid State Technology*, *63*(1s), 638-647.
- Allcoat, D., & von Mühlenen, A. (2018). Learning in virtual reality: Effects on performance, emotion and engagement. *Research in Learning Technology*, *26*.
- Alnagrat, A., Ismail, R. C., Idrus, S. Z. S., & Alfaqi, R. M. A. (2022). A review of extended reality (XR) technologies in the future of human education: Current trend and future opportunity. *Journal of Human Centered Technology*, *1*(2), 81-96.
- Altman, M., Huang, T. T., & Breland, J. Y. (2018). Design thinking in health care. *Preventing chronic disease*, *15*, E117.
- Amiti, F. (2020). Synchronous and asynchronous E-learning. *European Journal of Open Education and E-Learning Studies*, *5*(2).
- Andersen, R., & Rustad, M. (2022). Using Minecraft as an educational tool for supporting collaboration as a 21st century skill. *Computers and Education Open*, *3*, 100094.
- Anderson, J. M., Aylor, M. E., & Leonard, D. T. (2008). Instructional design dogma: Creating planned learning experiences in simulation. *Journal of Critical Care*, *23*(4), 595-602.
- Anderson, T., & Dron, J. (2011). Three generations of distance education pedagogy. *International Review of Research in Open and Distributed Learning*, *12*(3), 80-97.
- Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research?. *Educational researcher*, *41*(1), 16-25.
- Angrosino, M. (2007). *Doing ethnographic and observational research*. Sage.
- Antonenko, P., Paas, F., Grabner, R., & Van Gog, T. (2010). Using electroencephalography to measure cognitive load. *Educational psychology review*, *22*(4), 425-438.

- Arbaugh, J. B., Cleveland-Innes, M., Diaz, S. R., Garrison, D. R., Ice, P., Richardson, J. C., & Swan, K. P. (2008). Developing a community of inquiry instrument: Testing a measure of the community of inquiry framework using a multi-institutional sample. *The internet and higher education*, *11*(3-4), 133-136.
- Arguel, A., Pachman, M., & Lockyer, L. (2018). Identifying epistemic emotions from activity analytics in interactive digital learning environments. In *Learning analytics in the classroom* (pp. 56-68). Routledge.
- Argyris, C., & Schön, D. A. (1997). Organizational learning: A theory of action perspective. *Reis*, (77/78), 345-348.
- Asoodar, M., Janesarvatan, F., Yu, H., & de Jong, N. (2024). Theoretical foundations and implications of augmented reality, virtual reality, and mixed reality for immersive learning in health professions education. *Advances in Simulation*, *9*(1), 36.
- Azuma, R. T. (1997). A survey of augmented reality. *Presence: teleoperators & virtual environments*, *6*(4), 355-385.
- Bacca, J., Baldiris, S., Fabregat, R., & Graf, S. (2014). Augmented reality trends in education: a systematic review of research and applications.
- Bailenson, J. (2018). *Experience on demand: What virtual reality is, how it works, and what it can do*. WW Norton & Company.
- Bakeman, R., & Gottman, J. M. (1997). *Observing interaction: An introduction to sequential analysis*. Cambridge university press.
- Bales, R. F. (1950). Interaction process analysis; a method for the study of small groups.
- Banakou, D., Hanumanthu, P. D., & Slater, M. (2016). Virtual embodiment of white people in a black virtual body leads to a sustained reduction in their implicit racial bias. *Frontiers in human neuroscience*, *10*, 601.
- Bandura, A. (1997). *Self-efficacy: The exercise of control* (Vol. 11). Freeman.
- Barab, S., & Squire, K. (2016). Design-based research: Putting a stake in the ground. In *Design-based research* (pp. 1-14). Psychology Press.
- Barrett, A. J., Pack, A., & Quaid, E. D. (2021). Understanding learners' acceptance of high-immersion virtual reality systems: Insights from confirmatory and exploratory PLS-SEM analyses. *Computers & Education*, *169*, 104214.
- Barsalou, L. W. (2008). Grounded cognition. *Annu. Rev. Psychol.*, *59*(1), 617-645.
- Bathmaker, A. M., Crozier, G., Davis, P., Ertl, H., Fuller, A., Hayward, G., ... & Parry, G. (2010). *Improving learning by widening participation in higher education* (pp. xxi-249). M. E. David (Ed.). London: Routledge.

- Beahm, L. A., & Bradshaw, C. P. (2023). Adapting evidence-based professional development models for online delivery and scale-up to practitioners in applied settings. In *Handbook of school mental health: Innovations in science and practice* (pp. 493-512). Cham: Springer International Publishing.
- Beaux, H., Karimi, P., Pop, O., & Clark, R. (2024, October). Guiding Empowerment Model: Liberating Neurodiversity in Online Higher Education. In *2024 IEEE Frontiers in Education Conference (FIE)* (pp. 1-9). IEEE.
- Beckman, S. L., & Barry, M. (2007). Innovation as a learning process: Embedding design thinking. *California management review*, *50*(1), 25-56.
- Beetham, H., & Sharpe, R. (Eds.). (2019). *Rethinking pedagogy for a digital age: Principles and practices of design*. Routledge.
- Beggs, T. A. (2000). Influences and Barriers to the Adoption of Instructional Technology.
- Beghetto, R. A. (2018). Structured uncertainty: How creativity thrives under constraints and uncertainty. In *Creativity under duress in education? Resistive theories, practices, and actions* (pp. 27-40). Cham: Springer International Publishing.
- Bergsteiner, H., Avery, G. C., & Neumann, R. (2010). Kolb's experiential learning model: critique from a modelling perspective. *Studies in continuing education*, *32*(1), 29-46.
- Bhandari, R., & Rainford, J. (2023). Exploring the transitions of neurodivergent access students to level one study: Narratives of study skills and support. *International Journal of Educational and Life Transitions*, *2*(1).
- Bhattacherjee, A. (2001). Understanding information systems continuance: An expectation-confirmation model. *MIS quarterly*, 351-370.
- Biesta, G. J. (2015). *Beautiful risk of education*. Routledge.
- Biocca, F., Harms, C., & Burgoon, J. K. (2003). Toward a more robust theory and measure of social presence: Review and suggested criteria. *Presence: Teleoperators & virtual environments*, *12*(5), 456-480.
- Birt, J., Stromberga, Z., Cowling, M., & Moro, C. (2018). Mobile mixed reality for experiential learning and simulation in medical and health sciences education. *Information*, *9*(2), 31.
- Bogers, S., van Kollenburg, J., Frens, J., & Djajadiningrat, T. (2016, June). Data-enabled-design: A situated exploration of rich interactions. In *Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems* (pp. 45-48).
- Bolton, G. (2012). Who is telling the story? The critical role of the narrator in reflective and reflexive writing. *Educational reflective practices*, (2012/1).
- Bolton, G. E., & Delderfield, R. (2018). Reflective practice: Writing and professional development.
- Bonfield, C. A., Salter, M., Longmuir, A., Benson, M., & Adachi, C. (2020). Transformation or evolution?: Education 4.0, teaching and learning in the digital age. *Higher education pedagogies*, *5*(1), 223-246.

- Bongomin, O., Yemane, A., Kembabazi, B., Malanda, C., Mwape, M. C., Mpofu, N. S., & Tigalana, D. (2020). The hype and disruptive technologies of industry 4.0 in major industrial sectors: A state of the art.
- Borsotti, V., Begel, A., & Bjørn, P. (2024). Neurodiversity and the accessible university: Exploring organizational barriers, access labor and opportunities for change. *Proceedings of the ACM on Human-Computer Interaction*, *8*(CSCW1), 1-27.
- Bouchard, S., Robillard, G., St-Jacques, J., Dumoulin, S., Patry, M. J., & Renaud, P. (2004, October). Reliability and validity of a single-item measure of presence in VR. In *The 3rd IEEE international workshop on haptic, audio and visual environments and their applications* (pp. 59-61). IEEE.
- Broadbent, J., & Poon, W. L. (2015). Self-regulated learning strategies & academic achievement in online higher education learning environments: A systematic review. *The internet and higher education*, *27*, 1-13.
- Brooke, J. (1996). SUS-A quick and dirty usability scale. *Usability evaluation in industry*, *189*(194), 4-7.
- Brookfield, S. D. (2005). The power of critical theory for adult learning and teaching. *The adult learner*, *85*(1), 43-48.
- Brouwer, A. M., Zander, T. O., & van Erp, J. B. (Eds.). (2015). *Using neurophysiological signals that reflect cognitive or affective state*. Frontiers Media SA.
- Brouwer, A. M., Zander, T. O., Van Erp, J. B., Korteling, J. E., & Bronkhorst, A. W. (2015). Using neurophysiological signals that reflect cognitive or affective state: six recommendations to avoid common pitfalls. *Frontiers in neuroscience*, *9*, 136.
- Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The journal of the learning sciences*, *2*(2), 141-178.
- Brown, T. (2008). Design thinking. *Harvard business review*, *86*(6), 84.
- Bruns, L., Saurbier, B., Voong, T. M., & Oehler, M. (2024, September). Presence and flow in virtual and mixed realities for music-related educational settings. In *2024 IEEE 5th International Symposium on the Internet of Sounds (IS2)* (pp. 1-7). IEEE.
- Bullen, J., & Roberts, L. (2019). Driving transformative learning within Australian Indigenous studies. *The Australian Journal of Indigenous Education*, *48*(1), 12-23.
- Burgstahler, S. E., & Cory, R. C. (Eds.). (2010). *Universal design in higher education: From principles to practice*. Harvard Education Press.
- Butt, R., Siddiqui, H., Soomro, R. A., & Asad, M. M. (2020). Integration of Industrial Revolution 4.0 and IOTs in academia: a state-of-the-art review on the concept of Education 4.0 in Pakistan. *Interactive Technology and Smart Education*, *17*(4), 337-354.

- Calago, M., Urgino, E., Del Campo, W., & Pimentel, J. (2024). Investigating the Effects of Different Distance Learning Modalities on Student Academic Performance in Technology Education Programs. *Vietnam Journal of Education*, 274-283.
- Cambi, F. (2018). La pedagogia sociale in Italia: una frontiera in costante movimento. *Rassegna di pedagogia: Pädagogische Umschau: trimestrale di cultura pedagogica: LXXVI, 1/2, 2018*, 31-42.
- Candy, P. C. (1991). *Self-Direction for Lifelong Learning. A Comprehensive Guide to Theory and Practice*. Jossey-Bass, 350 Sansome Street, San Francisco, CA 94104-1310.
- Ceneciro, C. C. (2025). Characterizing Workshops Promoting Motivated Engagement and Retention beyond the Sessions: Experiential Narratives from Education, Language and Social Science Instructors.
- Ceruti, M. (2018). *Il tempo della complessità*. Raffaello Cortina Editore.
- Chakraborty, S., Gonzalez-Triana, Y., Mendoza, J., & Galatro, D. (2023, April). Insights on mapping Industry 4.0 and Education 4.0. In *Frontiers in Education* (Vol. 8, p. 1150190). Frontiers.
- Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. sage.
- Cheng, K. H. (2023). An epistemic curiosity-evoking model for immersive virtual reality narrative reading: User experience and the interaction among epistemic curiosity, transportation, and attitudinal learning. *Computers & Education*, *201*, 104814.
- Chessa, M., & Solari, F. (2021). The sense of being there during online classes: analysis of usability and presence in web-conferencing systems and virtual reality social platforms. Behaviour & Information Technology, 40(12), 1237-1249.
- Chirico, A., & Gaggioli, A. (2019). When virtual feels real: Comparing emotional responses and presence in virtual and natural environments. *Cyberpsychology, Behavior, and Social Networking*, *22*(3), 220-226.
- Chirico, A., Cipresso, P., Yaden, D. B., Biassoni, F., Riva, G., & Gaggioli, A. (2017). Effectiveness of immersive videos in inducing awe: an experimental study. *Scientific reports*, *7*(1), 1218.
- Chirico, A., Ferrise, F., Cordella, L., & Gaggioli, A. (2018). Designing awe in virtual reality: An experimental study. *Frontiers in psychology*, *8*, 2351.
- Chirico, A., Pizzolante, M., Kitson, A., Gianotti, E., Riecke, B. E., & Gaggioli, A. (2022). Defining transformative experiences: A conceptual analysis. *Frontiers in Psychology*, *13*, 790300.
- Chirico, A., Yaden, D. B., Riva, G., & Gaggioli, A. (2016). The potential of virtual reality for the investigation of awe. *Frontiers in psychology*, *7*, 1766.
- Christie, M., Carey, M., Robertson, A., & Grainger, P. (2015). Putting transformative learning theory into practice. *Australian journal of adult learning*, *55*(1), 9-30.
- Clark, R. E. (Ed.). (2001). *Learning from media: Arguments, analysis, and evidence*. IAP.

- Clouder, L., Karakus, M., Cinotti, A., Ferreyra, M. V., Fierros, G. A., & Rojo, P. (2020). Neurodiversity in higher education: a narrative synthesis. *Higher Education*, *80*(4), 757-778.
- Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher*, *32*(1), 9-13.
- Coffield, F., Ecclestone, K., Hall, E., & Moseley, D. (2004). Learning styles and pedagogy in post-16 learning: A systematic and critical review.
- Colgan, A. D. (2016). The epistemology behind the educational philosophy of Montessori: Senses, concepts, and choice. *Philosophical Inquiry in Education*, *23*(2), 125-140.
- Collins, A. (1992). Toward a design science of education. In *New directions in educational technology* (pp. 15-22). Berlin, Heidelberg: Springer Berlin Heidelberg.
- Collins, S. L., Mueller, S., Wood, E. A., & Stetten, N. E. (2022). Transforming perspectives through virtual exchange: a US-Egypt partnership part 2. *Frontiers in Public Health*, *10*, 880638.
- Conole, G. (2012). *Designing for learning in an open world* (Vol. 4). Springer Science & Business Media.
- Conrad, M., Kablitz, D., & Schumann, S. (2024). Learning effectiveness of immersive virtual reality in education and training: A systematic review of findings. *Computers & Education: X Reality*, *4*, 100053.Dick, W., Carey, L., & Carey, J. O. (2001). The systematic design of instruction (5th). *New York: Longmann*.
- Cook, D. A., & Artino Jr, A. R. (2016). Motivation to learn: an overview of contemporary theories. *Medical education*, *50*(10), 997-1014.
- Costan, E., Gonzales, G., Gonzales, R., Enriquez, L., Costan, F., Suladay, D., ... & Ocampo, L. (2021). Education 4.0 in developing economies: A systematic literature review of implementation barriers and future research agenda. *Sustainability*, *13*(22), 12763.
- Crogman, H. T., Cano, V. D., Pacheco, E., Sonawane, R. B., & Boroon, R. (2025). Virtual reality, augmented reality, and mixed reality in experiential learning: Transforming educational paradigms. *Education Sciences*, *15*(3), 303.
- Cronin, M., & Connolly, C. (2007). Exploring the use of experiential learning workshops and reflective practice within professional practice development for post-graduate health promotion students. *Health Education Journal*, *66*(3), 286-303.
- Csikszentmihalyi, M. (2014). *Applications of flow in human development and education* (pp. 153-172). Dordrecht: Springer.
- Csikszentmihalyi, M., & Csikzentmihaly, M. (1990). *Flow: The psychology of optimal experience* (Vol. 1990, p. 1). New York: Harper & Row.
- Cuban, L. (2018). *The Flight of a Butterfly or the Path of a Bullet? Using Technology to Transform Teaching and Learning*. Harvard Education Press. 8 Story Street First Floor, Cambridge, MA 02138.

- Cummings, J. J., & Bailenson, J. N. (2016). How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. *Media psychology*, *19*(2), 272-309.
- Curran, V. R., Xu, X., Aydin, M. Y., & Meruvia-Pastor, O. (2023). Use of extended reality in medical education: an integrative review. *Medical Science Educator*, *33*(1), 275-286.
- D'Mello, S., & Graesser, A. (2012). Dynamics of affective states during complex learning. *Learning and Instruction*, *22*(2), 145-157.
- D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction, 29,* 153-170.
- Dai, H. M., Teo, T., Rappa, N. A., & Huang, F. (2020). Explaining Chinese university students' continuance learning intention in the MOOC setting: A modified expectation confirmation model perspective. *Computers & Education*, *150*, 103850.
- Darmawan, C., Ervandi, A. J., Hatip, A., & Tobing, V. M. T. L. (2025). The Effect of Using Minecraft: Education Edition on Students' Conceptual Understanding and Collaboration. *Jurnal Ilmu Pendidikan (JIP) STKIP Kusuma Negara*, *17*(1), 148-158.
- Darmawan, I., Anwar, M. S., Rahmatulloh, A., & Sulastri, H. (2022). Design thinking approach for user interface design and user experience on campus academic information systems. *JOIV: International Journal on Informatics Visualization*, *6*(2), 327-334.
- Davis, B., & Sumara, D. (2014). *Complexity and education: Inquiries into learning, teaching, and research*. Routledge.
- De Girolamo, M. V. (2020). L'apprendimento negli adulti: Knowles e Kolb. *AIF News Learning*, *14*(5), 1-6.
- De Jong, T. (2010). Cognitive load theory, educational research, and instructional design: Some food for thought. *Instructional science*, *38*(2), 105-134.
- Deci, E. L., & Ryan, R. M. (2000). The" what" and" why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological inquiry*, *11*(4), 227-268.
- Deci, E. L., & Ryan, R. M. (2012). Self-determination theory. *Handbook of theories of social psychology*, *1*(20), 416-436.
- Dede, C. (2009). Immersive interfaces for engagement and learning. *science*, *323*(5910), 66-69.
- Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational researcher*, *32*(1), 5-8.
- Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011, September). From game design elements to gamefulness: defining" gamification". In *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments* (pp. 9-15).
- Dewey, J. (1933). How we think: A restatement of the relation of reflective thinking to the educative process.

- Dewey, J. (1986, September). Experience and education. In *The educational forum* (Vol. 50, No. 3, pp. 241-252). Taylor & Francis Group.
- Di Leo, N., & Traetta, L. (2025). Crafting knowledge block by block: A systematic review on the educational potential of Minecraft in schools. *Italian Journal of Educational Technology*, *33*(1), 67-85.
- Di Natale, A. F., Bartolotta, S., Gaggioli, A., Riva, G., & Villani, D. (2024b). Exploring students' acceptance and continuance intention in using immersive virtual reality and metaverse integrated learning environments: The case of an Italian university course. Education and Information Technologies, 1-20.
- Di Natale, A. F., Repetto, C., & Villani, D. (2024a). Desktop-based virtual reality social platforms versus video conferencing platforms for online synchronous learning in higher education: An experimental study to evaluate students' learning gains and user experience. Journal of Computer Assisted Learning, 40(6), 3454- 3473.
- Di Natale, A. F., Repetto, C., Riva, G., & Villani, D. (2020). Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research. *British Journal of Educational Technology*, *51*(6), 2006-2033.
- Diana, B., Villani, D., Muzio, M., & Riva, G. (2012). La validazione italiana della Flow State Scale-FSS. In *Flow, benessere e prestazione eccellente. Dai modelli teorici alle applicazioni nello sport e in azienda* (pp. 123-142). FrancoAngeli.
- Dick, W., Carey, L., & Carey, J. O. (1985). The systematic design of instruction.
- Dorst, K. (2011). The core of 'design thinking'and its application. *Design studies*, *32*(6), 521-532.
- Dubovi, I. (2022). Cognitive and emotional engagement while learning with VR: The perspective of multimodal methodology. *Computers & Education*, *183*, 104495.
- Duffy, T. M. (1996). Constructivism: Implications for the design and delivery of instruction. *Handbook of research for educational communications and technology*, 170-198.
- Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public interest*, *14*(1), 4-58.
- Dunmoye, I. D., Rukangu, A., May, D., & Das, R. P. (2024). An exploratory study of social presence and cognitive engagement association in a collaborative virtual reality learning environment. *Computers & Education: X Reality*, *4*, 100054.
- Durgungoz, F. C., & Durgungoz, A. (2025). "Interactive lessons are great, but too much is too much": Hearing out neurodivergent students, Universal Design for Learning and the case for integrating more anonymous technology in higher education. *Higher Education*, 1-20.
- Edmondson, A. (1999). Psychological safety and learning behavior in work teams. *Administrative science quarterly*, *44*(2), 350-383.

- Ehlers, U. D. (2025). Future Skills im Vergleich–Zur Konstruktion eines allgemeinen Rahmenmodells für Zukunftskompetenzen in der akademischen Bildung. In *Hochschullehre lernen, verstehen und gestalten: Konzepte, Ideen, Erfahrungen* (pp. 285-300). Wiesbaden: Springer Fachmedien Wiesbaden.
- Engeser, S., & Rheinberg, F. (2008). Flow, performance and moderators of challenge-skill balance. *Motivation and emotion*, *32*(3), 158-172.
- Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change: How knowledge, confidence, beliefs, and culture intersect. *Journal of research on Technology in Education*, *42*(3), 255-284.
- Falgares, G., Venza, G., & Guarnaccia, C. (2017). Learning psychology and becoming psychologists: Developing professional identity through group experiential learning. *Psychology Learning & Teaching*, *16*(2), 232-247.
- Fallowfield, L., Jenkins, V., Farewell, V., Saul, J., Duffy, A., & Eves, R. (2002). Efficacy of a Cancer Research UK communication skills training model for oncologists: a randomised controlled trial. *The Lancet*, *359*(9307), 650-656.
- Fan, H., & Zhang, X. (2024, December). Impacts of Immersive Virtual Reality Devices on Learning Outcomes across Disciplines in Higher Education: A PRISMA-Based Systematic Review. In *Proceedings of the 2024 5th International Conference on Big Data Economy and Information Management* (pp. 104-110).
- Federighi, P. (2018). *Educazione in età adulta: ricerche, politiche, luoghi e professioni* (p. 422). Firenze University Press.
- Fenwick, T., Edwards, R., & Sawchuk, P. (2015). *Emerging approaches to educational research: Tracing the socio-material*. Routledge.
- Fernández-Cerero, J., Fernández-Batanero, J. M., & Montenegro-Rueda, M. (2025). Possibilities of Extended Reality in education. *Interactive Learning Environments*, *33*(1), 208-222.
- Fetherston, B., & Kelly, R. (2007). Conflict resolution and transformative pedagogy: A grounded theory research project on learning in higher education. *Journal of Transformative Education*, *5*(3), 262-285.
- Fiorella, L., & Mayer, R. E. (2015). *Learning as a generative activity*. Cambridge university press.
- Fisk, P. (2017, January). *Education 4.0… the future of learning will be dramatically different, in school and throughout life*.
- Flanders, N. A. (1970). Analyzing teaching behavior.
- Fong, C. J., Zaleski, D. J., & Leach, J. K. (2015). The challenge–skill balance and antecedents of flow: A meta-analytic investigation. *The Journal of Positive Psychology*, *10*(5), 425-446.
- Ford, C., McNally, D., & Ford, K. (2017). Using design-based research in higher education innovation. *Online Learning*, *21*(3), 50-67.

- Foreman-Brown, G., Fitzpatrick, E., & Twyford, K. (2023). Reimagining teacher identity in the post-Covid-19 university: becoming digitally savvy, reflective in practice, collaborative, and relational. *Educational and Developmental Psychologist*, *40*(1), 18-26.
- Fowler, C. (2015). Virtual reality and learning: Where is the pedagogy?. *British journal of educational technology*, *46*(2), 412-422.
- Frederiksen, J. G., Sørensen, S. M. D., Konge, L., Svendsen, M. B. S., Nobel-Jørgensen, M., Bjerrum, F., & Andersen, S. A. W. (2020). Cognitive load and performance in immersive virtual reality versus conventional virtual reality simulation training of laparoscopic surgery: a randomized trial. *Surgical endoscopy*, *34*(3), 1244-1252.
- Freire, P. (1970). Pedagogy of the Oppressed (trans. MB Ramos). *New York: Continuum*, *2005*.
- Frithioff, A., Frendø, M., Mikkelsen, P. T., Sørensen, M. S., & Andersen, S. A. W. (2020). Ultra-high-fidelity virtual reality mastoidectomy simulation training: a randomized, controlled trial. *European Archives of Oto-Rhino-Laryngology*, *277*(5), 1335-1341.
- Fullan, M. (2016). *The new meaning of educational change*. Teachers college press.
- Gaggioli, A. (2005). Optimal experience in ambient intelligence. *Ambient intelligence*, *3*, 35-43.
- Gaggioli, A. (2016). Transformative experience design. *Human computer confluence. Transforming human experience through symbiotic technologies*, 96-121.
- Gaggioli, A., Bartolotta, S., Riva, G., Malighetti, C., Villani, D., Di Natale, A. F., ... & Chirico, A. (2024). The Potential of eXtended Reality in Education: The Metaversity Project. In *Humane Metaverse, Reflections on Self, Education, Organizations and Society* (pp. 43-74). Vita e Pensiero, Milano.
- Gaggioli, A., Bassi, M., & Fave, A. D. (2003). Quality of experience in virtual environments. *Emerging Communication*, *5*, 121-136.
- Gaggioli, A., Mazzoni, E., Benvenuti, M., Galimberti, C., Bova, A., Brivio, E., ... & Chirico, A. (2020). Networked flow in creative collaboration: A mixed method study. In *Creative Learning in Digital and Virtual Environments* (pp. 68-95). Routledge.
- Gaggioli, A., Riva, G., Milani, L., & Mazzoni, E. (2012). *Networked flow: Towards an understanding of creative networks*. Springer Science & Business Media.
- Gaggioli, A., Villani, D., Serino, S., Banos, R., & Botella, C. (2019). Positive technology: Designing e-experiences for positive change. *Frontiers in psychology*, *10*, 1571.
- Garrison, D. R., & Arbaugh, J. B. (2007). Researching the community of inquiry framework: Review, issues, and future directions. *The Internet and higher education*, *10*(3), 157-172.
- Garrison, D. R., Anderson, T., & Archer, W. (1999). Critical inquiry in a text-based environment: Computer conferencing in higher education. *The internet and higher education*, *2*(2-3), 87-105.
- Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in entertainment (CIE)*, *1*(1), 20-20.

- Geertz, C. (1973). *Cultures*.
- Georgiou, Y., Tsivitanidou, O., & Ioannou, A. (2021). Learning experience design with immersive virtual reality in physics education. *Educational Technology Research and Development*, *69*(6), 3051-3080.
- Gestwicki, P., & McNely, B. (2012). A case study of a five-step design thinking process in educational museum game design. *Proceedings of Meaningful Play*, 2-30.
- Girondini, M., Mariano, M., Stanco, G., Gallace, A., & Zapparoli, L. (2025). Human bodies in virtual worlds: A systematic review of implicit sense of agency and ownership measured in immersive virtual reality environments. *Frontiers in Human Neuroscience*, *19*, 1553574.
- Goh, C., Leong, C., Kasmin, K., Hii, P., & Tan, O. (2017). Students' experiences, learning outcomes and satisfaction in e-learning. *Journal of E-learning and Knowledge Society*, *13*(2).
- Goh, P. S. C., & Abdul-Wahab, N. (2020). Paradigms to drive higher education 4.0. *International Journal of Learning, Teaching and Educational Research*, *19*(1), 159-171.
- Gold, R. L. (2017). Roles in sociological field observations. In *Sociological methods* (pp. 363-380). Routledge.
- Granić, A., & Marangunić, N. (2019). Technology acceptance model in educational context: A systematic literature review. *British Journal of Educational Technology*, *50*(5), 2572-2593.
- Grassini, S., & Laumann, K. (2020). Questionnaire measures and physiological correlates of presence: A systematic review. *Frontiers in psychology*, *11*, 349.
- Greenbaum, A., Strickler, E., Patterson, V., & Oluleye, B. (2025). (World) Building Transformation: Students and Teachers as CoCreators in OpenXR Learning Environments. *arXiv preprint arXiv:2506.22988*.
- Grier, R. A. (2015, September). How high is high? A meta-analysis of NASA-TLX global workload scores. In *Proceedings of the human factors and ergonomics society annual meeting* (Vol. 59, No. 1, pp. 1727-1731). Sage CA: Los Angeles, CA: Sage Publications.
- Guerra-Tamez, C. R. (2023). The impact of immersion through virtual reality in the learning experiences of art and design students: The mediating effect of the flow experience. *Education Sciences*, *13*(2), 185.
- Guilbaud, P., Guilbaud, T. C., & Jennings, D. (2021, July). Extended reality, pedagogy, and career readiness: A review of literature. In *International conference on human-computer interaction* (pp. 595-613). Cham: Springer International Publishing.
- Gunawardena, C. N., & Zittle, F. J. (1997). Social presence as a predictor of satisfaction within a computer-mediated conferencing environment. *American journal of distance education*, *11*(3), 8-26.
- Gupta, A., Yousaf, A., & Mishra, A. (2020). How pre-adoption expectancies shape post-adoption continuance intentions: An extended expectation-confirmation model. *International Journal of Information Management*, *52*, 102094.

- Gysels, M., Richardson, A., & Higginson, I. J. (2005). Communication training for health professionals who care for patients with cancer: a systematic review of training methods. *Supportive care in cancer*, *13*(6), 356-366.
- Habermas, J. (1985). *The theory of communicative action: Volume 1: Reason and the rationalization of society* (Vol. 1). Beacon press.
- Hamari, J., Koivisto, J., & Sarsa, H. (2014, January). Does gamification work?--a literature review of empirical studies on gamification. In *2014 47th Hawaii international conference on system sciences* (pp. 3025-3034). Ieee.
- Han, E., Miller, M. R., DeVeaux, C., Jun, H., Nowak, K. L., Hancock, J. T., ... & Bailenson, J. N. (2023). People, places, and time: a large-scale, longitudinal study of transformed avatars and environmental context in group interaction in the metaverse. *Journal of Computer-Mediated Communication*, *28*(2), zmac031.
- Han, E., Miller, M. R., Ram, N., Nowak, K. L., & Bailenson, J. N. (2022, May). Understanding group behavior in virtual reality: A large-scale, longitudinal study in the metaverse. In *72nd annual international communication association conference, Paris, France*.
- Han, E., Strate, I., Nowak, K. L., & Bailenson, J. N. (2024). How different training types and computer anxiety influence performance and experiences in virtual reality. *Media and Communication*, *12*.
- Hannigan, B. (2001). A discussion of the strengths and weaknesses of 'reflection'in nursing practice and education. *Journal of clinical nursing*, *10*(2), 278-283.
- Hart, S. G. (2006, October). NASA-task load index (NASA-TLX); 20 years later. In *Proceedings of the human factors and ergonomics society annual meeting* (Vol. 50, No. 9, pp. 904-908). Sage CA: Los Angeles, CA: Sage publications.
- Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology* (Vol. 52, pp. 139-183). North-Holland.
- Hartmann, T., Wirth, W., Schramm, H., Klimmt, C., Vorderer, P., Gysbers, A., ... & Sacau, A. M. (2015). The spatial presence experience scale (SPES). *Journal of Media Psychology*.
- Hassenzahl, M. (2010). *Experience design: Technology for all the right reasons* (Vol. 8). Morgan & Claypool Publishers.
- Hassenzahl, M. (2018). The thing and I: understanding the relationship between user and product. In *Funology 2: from usability to enjoyment* (pp. 301-313). Cham: Springer International Publishing.
- Hassenzahl, M., & Tractinsky, N. (2006). User experience-a research agenda. *Behaviour & information technology*, *25*(2), 91-97.
- Hasso Plattner Institute of Design at Stanford. (2010). An introduction to design thinking: Process guide. Stanford University. Retrieved from https://web.stanford.edu/~mshanks/MichaelShanks/files/509554.pdf

- Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of educational research*, *77*(1), 81-112.
- Hawkinson, E., Alizadeh, M., Anesa, P., Figueroa Jr, R., Hall, W., Barr, M., ... & Klaphake, J. (2024). Narrative inquiry into the challenges of implementing XR technologies in education: Voices from Future Hub 2023. In *Narrative Inquiry into the Challenges of Implementing XR Technologies in Education: Voices from Future Hub 2023* (pp. 1-48). Together Learning.
- Healey, M., & Jenkins, A. (2000). Kolb's experiential learning theory and its application in geography in higher education. *Journal of geography*, *99*(5), 185-195.
- Herrington, J., & Reeves, T. C. (2011). Using design principles to improve pedagogical practice and promote student engagement. In *Proceedings ASCILITE 2011-Changing Demands, Changing Directions*.
- Herrington, J., Reeves, T. C., & Oliver, R. (2009). *A guide to authentic e-learning*. Routledge.
- Hogan, C. (2002). *Understanding facilitation: Theory and principles*. Kogan Page Publishers.
- Hrastinski, S. (2008). Asynchronous and synchronous e-learning. *Educause quarterly*, *31*(4), 51-55.
- Huang, W. H. (2011). Evaluating learners' motivational and cognitive processing in an online game-based learning environment. *Computers in Human Behavior*, *27*(2), 694-704.
- Huerta, M., Goodson, P., Beigi, M., & Chlup, D. (2017). Graduate students as academic writers: writing anxiety, self-efficacy and emotional intelligence. *Higher Education Research & Development*, *36*(4), 716-729.
- Huk, T. (2021). From education 1.0 to education 4.0-challenges for the contemporary school. *The New Educational Review*, *66*, 36-46.
- İbili, E., Ölmez, M., Cihan, A., Bilal, F., İbili, A. B., Okumus, N., & Billinghurst, M. (2024). Investigation of learners' behavioral intentions to use metaverse learning environment in higher education: a virtual computer laboratory. *Interactive Learning Environments*, *32*(10), 5893-5918.
- Idrees, A., Morton, M., & Dabrowski, G. (2022, May). Advancing extended reality teaching and learning opportunities across the disciplines in higher education. In *2022 8th international conference of the immersive learning research network (iLRN)* (pp. 1-8). IEEE.
- Illeris, K. (2004). Transformative learning in the perspective of a comprehensive learning theory. *Journal of Transformative education*, *2*(2), 79-89.
- Issitt, M. (1999). Towards the development of anti-oppressive reflective practice: The challenge for multi-disciplinary working. *Journal of practice teaching in social work and health*, *2*(2), 21-36.
- Issitt, M. (2003). Reflecting on reflective practice for professional education and development in health promotion. *Health education journal*, *62*(2), 173-188.
- Jarvis, P. (2012). *Adult learning in the social context*. Routledge.
- Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies*, *23*(4), 1515-1529.

- Jeunet, C., N'Kaoua, B., & Lotte, F. (2016). Advances in user-training for mental-imagery-based BCI control: Psychological and cognitive factors and their neural correlates. *Progress in brain research, 228,* 3-35.
- Johnson, D. W., & Johnson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. *Educational researcher*, *38*(5), 365-379.
- Johnson-Glenberg, M. C. (2018). Immersive VR and education: Embodied design principles that include gesture and hand controls. *Frontiers in Robotics and AI*, *5*, 375272.
- Jonassen, D. H., & Rohrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. *Educational technology research and development*, *47*(1), 61-79.
- Jones, C., Reichard, C., & Mokhtari, K. (2003). ARE STUDENTS'LEARNING STYLES DISCIPLINE SPECIFIC?. *Community College Journal of Research &Practice*, *27*(5), 363-375.
- Kang, M. J., Hsu, M., Krajbich, I. M., Loewenstein, G., McClure, S. M., Wang, J. T. Y., & Camerer, C. F. (2009). The wick in the candle of learning: Epistemic curiosity activates reward circuitry and enhances memory. Psychological science, 20(8), 963-973.
- Karsten, I., & van Zyl, A. (2022). Design-based research (DBR) as an effective tool to create context-sensitive and data-informed student success initiatives. *Journal of Student Affairs in Africa*, *10*(1), 15-31.
- Karthik, B. S. S., Chandrasekhar, B. B., David, R., & Kumar, A. K. (2019). Identification of instructional design strategies for an effective e-learning experience. *The Qualitative Report*, *24*(7), 1537-1555.
- Karunaratne, T. (2021). For learning analytics to be sustainable under GDPR—Consequences and way forward. *Sustainability*, *13*(20), 11524.
- Kaufman, J. C., & Sternberg, R. J. (Eds.). (2010). *The Cambridge handbook of creativity*. Cambridge University Press.
- Kee, T., Zhang, H., & King, R. B. (2024). An empirical study on immersive technology in synchronous hybrid learning in design education. *International Journal of Technology and Design Education*, *34*(3), 1243-1273.
- Keller, J. M. (1987a). Development and use of the ARCS model of instructional design. *Journal of instructional development*, *10*(3), 2-10.
- Keller, J. M. (1987b). Strategies for stimulating the motivation to learn. *Performance and instruction*, *26*(8), 1-7.
- Keller, J. M. (2009). *Motivational design for learning and performance: The ARCS model approach*. Springer Science & Business Media.
- Keskitalo, T., & Saukkoriipi, K. (2025). Co-designing a pedagogical model for immersive virtual environments in healthcare education. *Interactive Learning Environments*, 1-11.

- Khan, R., Vernooij, J., Salvatori, D., & Hierck, B. P. (2025). Assessing Cognitive Load Using EEG and Eye-Tracking in 3-D Learning Environments: A Systematic Review. *Multimodal Technologies and Interaction*, *9*(9), 99.
- Killough, D., Ji, T. F., Zhang, K., Hu, Y., Huang, Y., Du, R., & Zhao, Y. (2024). XR for All: Understanding Developer Perspectives on Accessibility Integration in Extended Reality. *arXiv preprint arXiv:2412.16321*.
- Kilteni, K., Groten, R., & Slater, M. (2012). The sense of embodiment in virtual reality. *Presence: Teleoperators and Virtual Environments*, *21*(4), 373-387.
- Kirschner, P. A., Ayres, P., & Chandler, P. (2011). Contemporary cognitive load theory research: The good, the bad and the ugly. *Computers in Human Behavior*, *27*(1), 99-105.
- Kitchenham, A. (2008). The evolution of John Mezirow's transformative learning theory. *Journal of transformative education*, *6*(2), 104-123.
- Kitchin, R. (2014). *The data revolution: Big data, open data, data infrastructures and their consequences*. Sage.
- Knowles, M. S. (1978). The Adult. *Learner: A Neglected Species-2nd Ed-Houston, TK: Gulf Publishing Company*.
- Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)?. *Contemporary issues in technology and teacher education*, *9*(1), 60-70.
- Kolb, A. Y. (2021). The Kolb Experiential Learning Profile. *Home Retrieved*, 1-154.
- Kolb, A. Y., & Kolb, D. A. (2006). Learning styles and learning spaces: A review of the multidisciplinary application of experiential learning theory in higher education. In *Learning styles and learning: A key to meeting the accountability demands in education* (pp. 45-91).
- Kolb, A. Y., & Kolb, D. A. (2009). The learning way: Meta-cognitive aspects of experiential learning. *Simulation & gaming*, *40*(3), 297-327.
- Kolb, D. A. (1984). Experience as the source of learning and development. *Upper Sadle River: Prentice Hall*.
- Kolb, D. A. (2007). *The Kolb learning style inventory*. Boston, MA: Hay Resources Direct.
- Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*. FT press.
- Kort, B., Reilly, R., & Picard, R. W. (2001, August). An affective model of interplay between emotions and learning: Reengineering educational pedagogy-building a learning companion. In *Proceedings IEEE international conference on advanced learning technologies* (pp. 43-46). IEEE.
- Kreijns, K., Xu, K., & Weidlich, J. (2022). Social presence: Conceptualization and measurement. *Educational psychology review*, *34*(1), 139-170.
- Krüger, J. M., Buchner, J., Altmeyer, K., Georgiou, Y., Hoyer, C., Palzer, K., ... & Bodemer, D. (2025). Towards a Transformative Framework for AR Learning and Instruction Through the Lenses of

Research and Practice: An Interdisciplinary Community Workshop. *Immersive Learning Research-Practitioner*, 24-28.

- Küçük, S., Kapakin, S., & Göktaş, Y. (2016). Learning anatomy via mobile augmented reality: Effects on achievement and cognitive load. *Anatomical sciences education*, *9*(5), 411-421.
- Kuhn, T. S. (1997). *The structure of scientific revolutions* (Vol. 962). Chicago: University of Chicago press.
- Kuleto, V., P, M. I., Stanescu, M., Ranković, M., Šević, N. P., Păun, D., & Teodorescu, S. (2021). Extended reality in higher education, a responsible innovation approach for generation y and generation z. *Sustainability*, *13*(21), 11814.
- Kurt, S. (2017, August 29; updated December 16, 2018). ADDIE Model: Instructional Design [Infographic]. Educational Technology. Retrieved from https://educationaltechnology.net/the-addie-model-instructional-design/
- Laurillard, D. (2013). *Teaching as a design science: Building pedagogical patterns for learning and technology*. Routledge.
- Laurillard, D., Kennedy, E., Charlton, P., Wild, J., & Dimakopoulos, D. (2018). Using technology to develop teachers as designers of TEL: Evaluating the learning designer. *British Journal of Educational Technology*, *49*(6), 1044-1058.
- LaViola Jr, J. J. (2000). A discussion of cybersickness in virtual environments. *ACM Sigchi Bulletin*, *32*(1), 47-56.
- Lee, H., & Hwang, Y. (2022). Technology-enhanced education through VR-making and metaverse-linking to foster teacher readiness and sustainable learning. *Sustainability*, *14*(8), 4786.
- Lee, J. Y., de Jong, N., Donkers, J., Jarodzka, H., & van Merriënboer, J. J. (2023). Measuring cognitive load in virtual reality training via pupillometry. *IEEE Transactions on Learning Technologies*, *17*, 704-710.
- Lee, K. M. (2004). Presence, explicated. *Communication theory*, *14*(1), 27-50.
- Lee, M. C. (2010). Explaining and predicting users' continuance intention toward e-learning: An extension of the expectation–confirmation model. *Computers & education*, *54*(2), 506-516.
- Lee, S. W. Y., & Tsai, C. C. (2011). Students' perceptions of collaboration, self-regulated learning, and information seeking in the context of Internet-based learning and traditional learning. *Computers in human behavior*, *27*(2), 905-914.
- Lee, Y. H., Hsieh, Y. C., & Hsu, C. N. (2011). Adding innovation diffusion theory to the technology acceptance model: Supporting employees' intentions to use e-learning systems. *Journal of Educational Technology & Society*, *14*(4), 124-137.
- Lewis, L. H., & Williams, C. J. (1994). Experiential learning: Past and present. *New directions for adult and continuing education*, *1994*(62), 5-16.

- Li, L., Zhu, M. L., Shi, Y. Q., & Yang, L. L. (2023). Influencing factors of self-regulated learning of medical-related students in a traditional Chinese medical university: a cross-sectional study. *BMC medical education*, *23*(1), 87.
- Liedtka, J. (2015). Perspective: Linking design thinking with innovation outcomes through cognitive bias reduction. *Journal of product innovation management*, *32*(6), 925-938.
- Liedtka, J. (2018). Why design thinking works. *Harvard Business Review*, *96*(5), 72-79.
- Lincoln, Y. S., & Guba, E. G. (1985). Naturalistic inquiry. Newberry Park.
- Litman, J. (2005). Curiosity and the pleasures of learning: Wanting and liking new information. Cognition and emotion, 19(6), 793-814.
- Loderer, K., Pekrun, R., & Lester, J. C. (2020). Beyond cold technology: A systematic review and meta-analysis on emotions in technology-based learning environments. *Learning and instruction*, *70*, 101162.
- Longo, L., & Orrú, G. (2022). Evaluating instructional designs with mental workload assessments in university classrooms. Behaviour & Information Technology, 41(6), 1199-1229.
- Lønne, T. F., Karlsen, H. R., Langvik, E., & Saksvik-Lehouillier, I. (2023). The effect of immersion on sense of presence and affect when experiencing an educational scenario in virtual reality: A randomized controlled study. *Heliyon*, *9*(6).
- Lucchese, A., Padovano, A., & Facchini, F. (2025). Comprehensive Systematic Literature Review on Cognitive Workload: Trends on Methods, Technologies and Case Studies. *IET Collaborative Intelligent Manufacturing*, *7*(1), e70025.
- Luft, J., & Ingham, H. (1955). The Johari window, a graphic model of interpersonal awareness. *Proceedings of the western training laboratory in group development*, *246*, 2014-2003.
- Ma, X., Monfared, R., Grant, R., & Goh, Y. M. (2024). Determining cognitive workload using physiological measurements: pupillometry and heart-rate variability. *Sensors*, *24*(6), 2010.
- MacLeod, A., Gordon, J., & Mann, K. (2009). Reflection and Reflective Practice in Health Professions Education: A Systematic Review.
- Madary, M., & Metzinger, T. K. (2016). Real virtuality: A code of ethical conduct. Recommendations for good scientific practice and the consumers of VR-technology. *Frontiers in Robotics and AI*, *3*, 180932.
- Makransky, G., & Lilleholt, L. (2018). A structural equation modeling investigation of the emotional value of immersive virtual reality in education. *Educational Technology Research and Development, 66*(5), 1141-1164.
- Makransky, G., & Mayer, R. E. (2022). Benefits of taking a virtual field trip in immersive virtual reality: Evidence for the immersion principle in multimedia learning. *Educational Psychology Review, 34*(3), 1771-1798.

- Makransky, G., & Petersen, G. B. (2019). Investigating the process of learning with desktop virtual reality: A structural equation modeling approach. *Computers & Education*, *134*, 15-30.
- Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational psychology review*, *33*(3), 937-958.
- Makransky, G., Lilleholt, L., & Aaby, A. (2017). Development and validation of the Multimodal Presence Scale for virtual reality environments: A confirmatory factor analysis and item response theory approach. *Computers in Human Behavior*, *72*, 276-285.
- Makransky, G., Petersen, G., & Immordino-Yang, M. H. (2019). Immersive virtual reality and learning. *Educational Psychology Review*, *31*, 799-825.
- Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and instruction, 60,* 225-236.
- Mann, S., Havens, J. C., Iorio, J., Yuan, Y., & Furness, T. (2018). All reality: values, taxonomy, and continuum, for virtual, augmented, eXtended/MiXed (X), Mediated (X, Y), and multimediated reality/intelligence. *AWE 2018*.
- Mann, S., Nolan, J., & Wellman, B. (2003). Sousveillance: Inventing and using wearable computing devices for data collection in surveillance environments. *Surveillance & society*, *1*(3), 331-355.
- Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023). Virtual reality in education: a review of learning theories, approaches and methodologies for the last decade. *Electronics*, *12*(13), 2832.
- Martin, F., Sun, T., Turk, M., & Ritzhaupt, A. D. (2021). A meta-analysis on the effects of synchronous online learning on cognitive and affective educational outcomes. *International Review of Research in Open and Distributed Learning*, *22*(3), 205-242.
- Mautone, P. D., & Mayer, R. E. (2001). Signaling as a cognitive guide in multimedia learning. *Journal of educational Psychology*, *93*(2), 377.
- Mayer, R. E. (2005). Cognitive theory of multimedia learning. *The Cambridge handbook of multimedia learning*, *41*(1), 31-48.
- Mayer, R. E. (2014). Based principles for designing multimedia instruction. *Copyright and Other Legal Notices*, *59*.
- Mayer, R. E. (2019). Computer games in education. *Annual review of psychology*, *70*(1), 531-549.
- Mayer, R. E., & Chandler, P. (2001). When learning is just a click away: Does simple user interaction foster deeper understanding of multimedia messages?. *Journal of educational psychology*, *93*(2), 390.
- Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational psychologist*, *38*(1), 43-52.

- McDowall, A., & Kiseleva, M. (2024). A rapid review of supports for neurodivergent students in higher education. Implications for research and practice. *Neurodiversity*, *2*, 27546330241291769.
- McKenney, S., & Reeves, T. (2018). *Conducting educational design research*. Routledge.
- Meinel, C., Leifer, L., & Plattner, H. (2011). Design thinking: Understand-improve-apply.
- Meinel, M., Eismann, T. T., Baccarella, C. V., Fixson, S. K., & Voigt, K. I. (2020). Does applying design thinking result in better new product concepts than a traditional innovation approach? An experimental comparison study. *European Management Journal*, *38*(4), 661-671.
- Merrill, M. D., Drake, L., Lacy, M. J., Pratt, J., & ID_2 Research Group. (1996). Reclaiming instructional design. *Educational Technology*, 5-7.
- Meyer, A., Rose, D. H., & Gordon, D. (2014). Universal design for learning: Theory and practice. *(No Title)*.
- Meyer, O. A., Omdahl, M. K., & Makransky, G. (2019). Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment. *Computers & Education*, *140*, 103603.
- Mezirow, J. (1991). *Transformative dimensions of adult learning*. Jossey-Bass, 350 Sansome Street, San Francisco, CA 94104-1310.
- Mezirow, J. (2000). *Learning as Transformation: Critical Perspectives on a Theory in Progress. The Jossey-Bass Higher and Adult Education Series*. Jossey-Bass Publishers, 350 Sansome Way, San Francisco, CA 94104.
- Miguel-Alonso, I., Checa, D., Guillen-Sanz, H., & Bustillo, A. (2024). Evaluation of the novelty effect in immersive virtual reality learning experiences. *Virtual Reality*, *28*(1), 27.
- Miguel-Alonso, I., Rodriguez-Garcia, B., Checa, D., & Bustillo, A. (2023). Countering the novelty effect: a tutorial for immersive virtual reality learning environments. *Applied Sciences*, *13*(1), 593.
- Mikropoulos, T. A., & Natsis, A. (2011). Educational virtual environments: A ten-year review of empirical research (1999–2009). *Computers & education*, *56*(3), 769-780.
- Milgram, P., & Colquhoun, H. (1999). A taxonomy of real and virtual world display integration. *Mixed reality: Merging real and virtual worlds*, *1*(1999), 1-26.
- Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, *77*(12), 1321-1329.
- Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, *77*(12), 1321-1329.
- Miller, E. J. (1990). Experiential learning in groups I. *1990*, 165-185.
- Miranda, J., Navarrete, C., Noguez, J., Molina-Espinosa, J. M., Ramírez-Montoya, M. S., Navarro-Tuch, S. A., ... & Molina, A. (2021). The core components of education 4.0 in higher education: Three case studies in engineering education. *Computers & Electrical Engineering*, *93*, 107278.

- Mirriahi, N., Dawson, S., & Hoven, D. (2012). Identifying key actors for technology adoption in higher education: A social network approach. *Future challenges, sustainable futures. Proceedings ascilite Wellington*, 664-574.
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers college record*, *108*(6), 1017-1054.
- Moneta, G. B. (2012). On the measurement and conceptualization of flow. In *Advances in flow research* (pp. 23-50). New York, NY: Springer New York.
- Moore, M. G. (1989). Three types of interaction.
- Moro, C., Birt, J., Stromberga, Z., Phelps, C., Clark, J., Glasziou, P., & Scott, A. M. (2021). Virtual and augmented reality enhancements to medical and science student physiology and anatomy test performance: A systematic review and meta-analysis. *Anatomical sciences education*, *14*(3), 368-376.
- Moro, C., Štromberga, Z., Raikos, A., & Stirling, A. (2017). The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anatomical sciences education*, *10*(6), 549-559.
- Morris, T. H. (2020). Experiential learning–a systematic review and revision of Kolb's model. *Interactive learning environments*, *28*(8), 1064-1077.
- Mortari, L. (2015). *Filosofia della cura* (pp. 1-225). Raffaello Cortina.
- Mottelson, A., Muresan, A., Hornbæk, K., & Makransky, G. (2023). A systematic review and meta-analysis of the effectiveness of body ownership illusions in virtual reality. *ACM transactions on computer-human interaction*, *30*(5), 1-42.
- Muis, K. R., Chevrier, M., & Singh, C. A. (2018). The role of epistemic emotions in personal epistemology and self-regulated learning. *Educational psychologist*, *53*(3), 165-184.
- Mulders, M., & Träg, K. H. (2023). Presence and flow as moderators in xr-based sustainability education. *Sustainability*, *15*(23), 16496.
- Mulhall, A. (2003). In the field: notes on observation in qualitative research. *Journal of advanced nursing*, *41*(3), 306-313.
- Muruganantham, G. (2015). Developing of E-content package by using ADDIE model. *International Journal of Applied Research*, *1*(3), 52-54.
- Nakamura, J., & Csikszentmihalyi, M. (2014). The concept of flow. In *Flow and the foundations of positive psychology: The collected works of Mihaly Csikszentmihalyi* (pp. 239-263). Dordrecht: Springer Netherlands.
- Nash-Luckenbach, D. M., & Friedman, Z. L. (2024). The neurodivergent college learner: faculty perceptions of supporting individuals with ADHD in higher education. *Quality Assurance in Education*, *32*(4), 597-610.

- Newman, S. (1999). Constructing and critiquing reflective practice. *Educational Action Research*, *7*(1), 145-163.
- Nielsen, J. (1994). *Usability engineering*. Morgan Kaufmann.
- Nielsen, S. L., Christensen, P. R., & Storvang, P. (2021). Does design thinking benefit ambidextrous dynamics between SME managers' entrepreneurial and administrative mindsets?. *The Design Journal*, *24*(5), 683-703.
- Norsworthy, C., Dimmock, J. A., Miller, D. J., Krause, A., & Jackson, B. (2023). Psychological flow scale (PFS): Development and preliminary validation of a new flow instrument that measures the core experience of flow to reflect recent conceptual advancements. *International Journal of Applied Positive Psychology*, *8*(2), 309-337.
- Nowak, K. L., & Biocca, F. (2003). The effect of the agency and anthropomorphism on users' sense of telepresence, copresence, and social presence in virtual environments. *Presence: Teleoperators & Virtual Environments*, *12*(5), 481-494.
- Obeidallah, R., Ahmad, A. A., & Qutishat, D. (2023). Challenges of Extended Reality Technology in Higher Education: A Review. *International Journal of Emerging Technologies in Learning*, *18*(14).
- Oh, C. S., Bailenson, J. N., & Welch, G. F. (2018). A systematic review of social presence: Definition, antecedents, and implications. *Frontiers in Robotics and AI*, *5*, 114.
- Olmos-Raya, E., Ferreira-Cavalcanti, J., Contero, M., Castellanos, M. C., Giglioli, I. A. C., & Alcañiz, M. (2018). Mobile virtual reality as an educational platform: A pilot study on the impact of immersion and positive emotion induction in the learning process. *EURASIA Journal of Mathematics, Science and Technology Education*, *14*(6), 2045-2057.
- Ørngreen, R., & Levinsen, K. (2017). Workshops as a research methodology. *The Electronic Journal of e-learning*, *15*(1), 70-81.
- Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational psychologist*, *38*(1), 1-4.
- Pardo, A., & Siemens, G. (2014). Ethical and privacy principles for learning analytics. *British journal of educational technology*, *45*(3), 438-450.
- Parker, J. (2011). A design-based research approach for creating effective online higher education courses. In *26th Annual Research Forum (Western Australian Institute for Educational Research Inc) Educational Possibilities*. 2011 Western Australian Institute for Educational Research Inc.
- Parong, J., & Mayer, R. E. (2018). Learning science in immersive virtual reality. *Journal of educational psychology*, *110*(6), 785.
- Parong, J., & Mayer, R. E. (2021a). Cognitive and affective processes for learning science in immersive virtual reality. *Journal of Computer Assisted Learning*, *37*(1), 226-241.

- Parong, J., & Mayer, R. E. (2021b). Learning about history in immersive virtual reality: Does immersion facilitate learning?. *Educational Technology Research and Development*, *69*(3), 1433-1451.
- Parrish, P. (2006). Design as storytelling. *TechTrends*, *50*(4), 72-82.
- Parrish, P. E. (2009). Aesthetic principles for instructional design. *Educational Technology Research and Development*, *57*(4), 511-528.
- Parrish, P. E., Wilson, B. G., & Dunlap, J. C. (2011). Learning experience as transaction: A framework for instructional design. *Educational Technology*, 15-22.
- Pastore, M., & Calcagnì, A. (2019). Measuring distribution similarities between samples: A distribution-free overlapping index. *Frontiers in psychology*, *10*, 1089.
- Patton, M. Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice*. Sage publications.
- Paul, L. A. (2014). *Transformative experience*. OUP Oxford.
- Paulsen, L., Dau, S., & Davidsen, J. (2024). Designing for collaborative learning in immersive virtual reality: A systematic literature review. *Virtual Reality*, *28*(1), 63.
- Pea, R. D., Biernacki, P., Bigman, M., Boles, K., Coelho, R., Docherty, V., ... & Vishwanath, A. (2023). Four surveillance technologies creating challenges for education. *Learning: Designing the Future*, 317.
- Peake, J. M., Kerr, G., & Sullivan, J. P. (2018). A critical review of consumer wearables, mobile applications, and equipment for providing biofeedback, monitoring stress, and sleep in physically active populations. *Frontiers in physiology*, *9*, 743.
- Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational psychology review*, *18*(4), 315-341.
- Pekrun, R. (2014). Emotions and Learning. Educational Practices Series-24. *UNESCO International Bureau of Education*.
- Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Academic emotions in students' self-regulated learning and achievement: A program of qualitative and quantitative research. *Educational psychologist*, *37*(2), 91-105.
- Pekrun, R., Vogl, E., Muis, K. R., & Sinatra, G. M. (2017). Measuring emotions during epistemic activities: The epistemically-related emotion scales. Cognition and Emotion, 31(6), 1268-1276.
- Pekrun, R., Vogl, E., Muis, K. R., & Sinatra, G. M. (2017). Measuring emotions during epistemic activities: The epistemically-related emotion scales. *Cognition and Emotion*, *31*(6), 1268-1276.
- Pellas, N., Mystakidis, S., & Kazanidis, I. (2021). Immersive Virtual Reality in K-12 and Higher Education: A systematic review of the last decade scientific literature. *Virtual Reality*, *25*(3), 835-861.
- Perkins, D. N., & Salomon, G. (1992). Transfer of learning. *International encyclopedia of education*, *2*(2), 6452-6457.

- Perkins, E. R., Simnett, I., & Wright, L. (Eds.). (1999). *Evidence-based health promotion*. Chichester: Wiley.
- Persada, S. F., Miraja, B. A., Nadlifatin, R., Belgiawan, P. F., Redi, P., A., & Lin, S. C. (2021). Determinants of students' intention to continue using online private tutoring: An expectationconfirmation model (ECM) approach. Technology Knowledge and Learning, 1–14.
- Pfaller, M., Kroczek, L. O., Lange, B., Fülöp, R., Müller, M., & Mühlberger, A. (2021). Social presence as a moderator of the effect of agent behavior on emotional experience in social interactions in virtual reality. *Frontiers in Virtual Reality*, *2*, 741138.
- Pfeiffer, L. J., Knobloch, N. A., Tucker, M. A., & Hovey, M. (2022). Issues-360TM: an analysis of transformational learning in a controversial issues engagement initiative. *The Journal of Agricultural Education and Extension*, *28*(4), 439-458.
- Piaget, J., & Cook, M. (1952). *The origins of intelligence in children* (Vol. 8, No. 5, pp. 18-1952). New York: International universities press.
- Poggianti, C., Chessa, S., Pelagatti, S., & Kocian, A. (2025). Immersive technologies for inclusive digital education: a systematic survey. *Human Behavior and Emerging Technologies*, *2025*(1), 8888303.
- Pollo, M. (2004). *Manuale di pedagogia sociale* (Vol. 8). FrancoAngeli.
- Porter, W. W., & Graham, C. R. (2016). Institutional drivers and barriers to faculty adoption of blended learning in higher education. *British Journal of Educational Technology*, *47*(4), 748-762.
- Poupard, M., Larrue, F., Sauzéon, H., & Tricot, A. (2025). A systematic review of immersive technologies for education: Learning performance, cognitive load and intrinsic motivation. *British Journal of Educational Technology*, *56*(1), 5-41.
- Rabaa'i, A. A., ALmaati, S. A., & Zhu, X. (2021). Students' continuance intention to use Moodle: An expectation-confirmation model approach. Interdisciplinary Journal of Information Knowledge and Management, 16, 397.
- Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & education*, *147*, 103778.
- Rauschnabel, P. A., Felix, R., Hinsch, C., Shahab, H., & Alt, F. (2022). What is XR? Towards a framework for augmented and virtual reality. *Computers in human behavior*, *133*, 107289.
- Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important?. *Review of educational research*, *82*(3), 330-348.
- Redecker, C., & Punie, Y. (2017). Digital competence of educators. *Edited by Yves Punie*.
- Redecker, C., Ala-Mutka, K., & Punie, Y. (2010). Learning 2.0-The impact of social media on learning in Europe. *Policy brief. JRC Scientific and Technical Report. EUR JRC56958 EN, available from: http://bit. ly/cljlpq [Accessed 6 th February 2011]*.

- Reeves, T. (2006). Design research from a technology perspective. In *Educational design research* (pp. 64-78). Routledge.
- Reiser, R. A. (2001). A history of instructional design and technology: Part II: A history of instructional design. *Educational technology research and development*, *49*(2), 57-67.
- Relf, M., & Heath, B. (2007). Experiential workshops. In *Education in palliative care: Building a culture of learning*. Oxford University Press Oxford.
- Renninger, K. A., & Bachrach, J. E. (2015). Studying triggers for interest and engagement using observational methods. *Educational Psychologist*, *50*(1), 58-69.
- Rettinger, M., Jiang, X., Yang, J., & Rigoll, G. (2024, March). Visual Complexity in VR: implications for cognitive load. In *2024 IEEE conference on virtual reality and 3d user interfaces abstracts and workshops (VRW)* (pp. 783-784). IEEE.
- Richardson, A. E., Montello, D. R., & Hegarty, M. (1999). Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory & cognition, 27*(4)*,* 741-750.
- Richardson, J. C., Maeda, Y., Lv, J., & Caskurlu, S. (2017). Social presence in relation to students' satisfaction and learning in the online environment: A meta-analysis. *Computers in Human Behavior*, *71*, 402-417.
- Richardson, J., Swan, K., Lowenthal, P., & Ice, P. (2016, April). Social presence in online learning: Past, present, and future. In *Global Learn* (pp. 477-483). Association for the Advancement of Computing in Education (AACE).
- Richmond, A. S., Ropp, A., Bradford, J., Ignizio, G. S., Hammond, J., Mowder, D., & Bittmann, J. M. (2024). An ecologically valid study of the testing effect across academic disciplines: A focus on higher-vs. lower-level learning. *College Teaching*, *72*(2), 74-81.
- Riva, G. (2003). Ambient intelligence in health care. *CyberPsychology & Behavior*, *6*(3), 295-300.
- Riva, G. (2008). From virtual to real body: virtual reality as embodied technology. *J. Cyber Ther. Rehabil*, *1*, 7-22.
- Riva, G., & Waterworth, J. A. (2003). Presence and the Self: A cognitive neuroscience approach. *Presence connect*, *3*(3).
- Riva, G., Baños, R. M., Botella, C., Mantovani, F., & Gaggioli, A. (2016). Transforming experience: the potential of augmented reality and virtual reality for enhancing personal and clinical change. *Frontiers in psychiatry*, *7*, 164.
- Riva, G., Bernardelli, L., Browning, M. H., Castelnuovo, G., Cavedoni, S., Chirico, A., ... & Wiederhold, B. K. (2020). COVID feel good—an easy self-help virtual reality protocol to overcome the psychological burden of coronavirus. *Frontiers in psychiatry*, *11*, 563319.
- Riva, G., Davide, F., & IJsselsteijn, W. A. (2003). Being there: The experience of presence in mediated environments. *Being there: Concepts, effects and measurement of user presence in synthetic environments*, *5*, 2003.

- Riva, G., Di Lernia, D., Sajno, E., Sansoni, M., Bartolotta, S., Serino, S., ... & Wiederhold, B. K. (2021). Virtual reality therapy in the metaverse: Merging VR for the outside with VR for the inside. *Annual Review of Cybertherapy & Telemedicine*, *19*(3-8).
- Riva, G., Mantovani, F., Capideville, C. S., Preziosa, A., Morganti, F., Villani, D., ... & Alcañiz, M. (2007). Affective interactions using virtual reality: the link between presence and emotions. *Cyberpsychology & behavior*, *10*(1), 45-56.
- Riva, G., Serino, S., Chirico, A., & Gaggioli, A. (2019). Positive technology: From communication to positive experience. In *The Routledg*
- Riva, G., Wiederhold, B. K., & Mantovani, F. (2019). Neuroscience of virtual reality: from virtual exposure to embodied medicine. *Cyberpsychology, behavior, and social networking*, *22*(1), 82-96.
- Rivers, K., Aggleton, P., & Whitty, G. (1998). Professional preparation and development for health promotion: a review of literature. *Health Education Journal*, *57*(3), 254-262.
- Roberts, J. (2018). From the editor: The possibilities and limitations of experiential learning research in higher education. *Journal of Experiential Education*, *41*(1), 3-7.
- Roediger III, H. L., & Karpicke, J. D. (2006). Test-enhanced learning: Taking memory tests improves long-term retention. *Psychological science*, *17*(3), 249-255.
- Rogers, C. R. (1969). *Freedom to Learn (Merrill, Columbus, Ohio)*.
- Rowland, G. (1993). Designing and instructional design. *Educational technology research and development*, *41*(1), 79-91.
- Ryan, M. L. (2015). *Narrative as virtual reality 2: Revisiting immersion and interactivity in literature and electronic media*. JHU press.
- Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American psychologist*, *55*(1), 68.
- Sailer, M., & Homner, L. (2020). The gamification of learning: A meta-analysis. *Educational psychology review*, *32*(1), 77-112.
- Sailer, M., & Homner, L. (2020). The gamification of learning: A meta-analysis. *Educational psychology review*, *32*(1), 77-112.
- Salmon, G., Nie, M., & Edirisingha, P. (2010). Developing a five-stage model of learning in Second Life. *Educational Research*, *52*(2), 169-182.
- Sánchez-López, I., Roig-Vila, R., & Pérez-Rodríguez, A. (2022). Metaverse and education: the pioneering case of Minecraft in immersive digital learning.
- Saturday, J. M. (2003). The influence of early internalized experiences on adult learning groups.
- Schön, D. A. (1987). Educating the reflective practitioner.
- Schön, D. A. (2017). *The reflective practitioner: How professionals think in action*. Routledge.

- Schrader, C., Diekmann, C., Schulz, P., Mack, N., Bohrmann-Linde, C., & Zeller, D. (2024). Hands-on training: Effects on virtual presence, learning-centered emotions, cognitive load and learning outcome when learning with virtual reality. *Computers in Human Behavior Reports*, *16*, 100487.
- Schubert, S., Pekrun, R., & Ufer, S. (2023). The role of epistemic emotions in undergraduate students' proof construction. ZDM–Mathematics Education, 55(2), 299-314.
- Schubert, T., Friedmann, F., & Regenbrecht, H. (2001). The experience of presence: Factor analytic insights. *Presence: Teleoperators & Virtual Environments*, *10*(3), 266-281.
- Schwaiger, M., Krajnčan, M., Vukovič, M., Jenko, M., & Doz, D. (2024). Educators' opinions about VR/AR/XR: An exploratory study. *Education and Information Technologies*, *29*(18), 24861-24880.
- Seale, J. (2013). *E-learning and disability in higher education: Accessibility research and practice*. Routledge.
- See, Z. S., Ledger, S., Goodman, L., Matthews, B., Jones, D., Fealy, S., & Amin, M. (2023). Playable experiences through technologies: Opportunities and challenges for teaching simulation learning and extended reality solution creation. *The Journal of Information Technology Education: Innovations in Practice*, *22*, 67-90.
- Seels, B. B., & Richey, R. C. (2012). *Instructional technology: The definition and domains of the field*. Iap.
- Selwyn, N. (2019). *Should robots replace teachers?: AI and the future of education*. John Wiley & Sons.
- Selwyn, N., Hillman, T., Eynon, R., Ferreira, G., Knox, J., Macgilchrist, F., & Sancho-Gil, J. M. (2020). What's next for Ed-Tech? Critical hopes and concerns for the 2020s. *Learning, Media and Technology*, *45*(1), 1-6.
- Shams, L., & Seitz, A. R. (2008). Benefits of multisensory learning. *Trends in cognitive sciences*, *12*(11), 411-417.
- Sharma, Y., Suri, A., Sijariya, R., & Jindal, L. (2025). Role of education 4.0 in innovative curriculum practices and digital literacy–A bibliometric approach. *E-Learning and Digital Media*, *22*(1), 1-32.
- Shen, C. W., Ho, J. T., Ly, P. T. M., & Kuo, T. C. (2019). Behavioural intentions of using virtual reality in learning: perspectives of acceptance of information technology and learning style. *Virtual Reality*, *23*(3), 313-324.
- Shernoff, D. J., Csikszentmihalyi, M., Schneider, B., & Shernoff, E. S. (2014). Student engagement in high school classrooms from the perspective of flow theory. In *Applications of flow in human development and education: The collected works of Mihaly Csikszentmihalyi* (pp. 475-494). Dordrecht: Springer Netherlands.
- Shi, F., Wu, Y., & He, R. (2025, April). Meta-analysis reveals the effectiveness evaluation of blended learning models across different academic disciplines. In *Forum for Education Studies* (Vol. 3, No. 2, pp. 2501-2501).

- Singh, O. B. (2009). *Development and validation of a web-based module to teach metacognitive learning strategies to students in higher education*. University of South Florida.
- Skarbez, R., Smith, M., & Whitton, M. C. (2021). Revisiting Milgram and Kishino's reality-virtuality continuum. *Frontiers in Virtual Reality*, *2*, 647997.
- Skulmowski, A., & Rey, G. D. (2018). Embodied learning: introducing a taxonomy based on bodily engagement and task integration. *Cognitive research: principles and implications*, *3*(1), 6.
- Skulmowski, A., & Xu, K. M. (2022). Understanding cognitive load in digital and online learning: A new perspective on extraneous cognitive load. *Educational psychology review*, *34*(1), 171-196.
- Slater, M. (2003). A note on presence terminology. *Presence connect*, *3*(3), 1-5.
- Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and virtual environments*, *6*(6), 603-616.
- Smith, H. J., & Neff, M. (2018, April). Communication behavior in embodied virtual reality. In *Proceedings of the 2018 CHI conference on human factors in computing systems* (pp. 1-12).
- Spradley, J. (1980). Participant Observation" Holt, Rineart and WinSton, Inc. *New York*.
- Srinivasan, V., & Murthy, H. (2021). Improving reading and comprehension in K-12: Evidence from a large-scale AI technology intervention in India. *Computers and Education: Artificial Intelligence*, *2*, 100019.
- St Leger, L. (2001). Schools, health literacy and public health: possibilities and challenges. *Health promotion international*, *16*(2), 197-205.
- Stanney, K., Fidopiastis, C., & Foster, L. (2020). Virtual reality is sexist: but it does not have to be. *Frontiers in Robotics and AI*, *7*, 4.
- Stark, S., Stronach, I., & Cooke, P. (1999). Reflection and the gap between practice, education and research in nursing. *Journal of practice teaching in social work and health*, *2*(2), 6-20.
- Stein, B. E., & Stanford, T. R. (2008). Multisensory integration: current issues from the perspective of the single neuron. *Nature reviews neuroscience*, *9*(4), 255-266.
- Steinfeld, E., & Maisel, J. (2012). *Universal design: Creating inclusive environments*. John Wiley & Sons.
- Steinicke, F., Lehmann-Willenbrock, N., & Meinecke, A. L. (2020, October). A first pilot study to compare virtual group meetings using video conferences and (immersive) virtual reality. In *Proceedings of the 2020 ACM symposium on spatial user interaction* (pp. 1-2).
- Stratton, G. M. (1897). Vision without inversion of the retinal image. *Psychological review*, *4*(4), 341.
- Sun Joo, C., & Lee Jin, C. (2024). Expanding horizons: fostering creativity and curiosity through spherical video-based virtual reality in project-based language learning. *TESOL Quarterly*, *58*(4), 1786-1800.

- Sutherland, I. E. (1965, May). The ultimate display. In *Proceedings of the IFIP Congress* (Vol. 2, No. 506-508, pp. 506-508).
- Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and instruction*, *4*(4), 295-312.
- Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. *The Cambridge handbook of multimedia learning*, *3*(2), 19-30.
- Sweller, J. (2010). Cognitive load theory: Recent theoretical advances.
- Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational psychology review, 22*(2), 123-138.
- Taheri, A., & Aguayo, C. (2022). XR technologies and experience-based learning. *Pacific Journal of Technology Enhanced Learning*, *4*(1), 44-45.
- Taylor, E. W., & Snyder, M. J. (2012). A critical review of research on transformative learning theory, 2006-2010. *The handbook of transformative learning: Theory, research, and practice*, 37-55.
- Tcherdakoff, N. A., Marshall, P., Dowthwaite, A., Bird, J., & Cox, A. L. (2025, June). Burnout by Design: How Digital Systems Overburden Neurodivergent Students in Higher Education. In *Proceedings of the 4th Annual Symposium on Human-Computer Interaction for Work* (pp. 1-18).
- Teng, Z., Cai, Y., Gao, Y., Zhang, X., & Li, X. (2022). Factors affecting learners' adoption of an educational metaverse platform: An empirical study based on an extended UTAUT model. *Mobile Information Systems*, *2022*(1), 5479215.
- Tondeur, J., Pareja Roblin, N., Van Braak, J., Voogt, J., & Prestridge, S. (2017). Preparing beginning teachers for technology integration in education: Ready for take-off?. *Technology, Pedagogy and Education*, *26*(2), 157-177.
- Tramma, S. (2019). *L'educazione sociale*. Gius. Laterza & Figli Spa.
- Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychological bulletin*, *63*(6), 384.
- Turucz, E., Truta, S. T., Paşca, M. D., Jerzicska, E., Boeriu, C. M., Szederjesi, J., & Azamfirei, L. (2021). Educational design research, an innovative method to investigate virtual reality applications in disaster management training programs. *Acta Marisiensis-Seria Medica*, *67*(1).
- Tze, V. M., Daniels, L. M., & Klassen, R. M. (2016). Evaluating the relationship between boredom and academic outcomes: A meta-analysis. *Educational Psychology Review*, *28*(1), 119-144.
- Tzimas, D., & Demetriadis, S. (2021). Ethical issues in learning analytics: A review of the field. *Educational Technology Research and Development*, *69*(2), 1101-1133.
- Uhl, J. C., Neundlinger, K., & Regal, G. (2023). Social presence as a training resource: comparing VR and traditional training simulations. *Research in Learning Technology*, *31*.
- Ulibarri, N., E Cravens, A., Cornelius, M., Royalty, A., & Svetina Nabergoj, A. (2014). Research as design: Developing creative confidence in doctoral students through design thinking.

- Um, E., Plass, J. L., Hayward, E. O., & Homer, B. D. (2012). Emotional design in multimedia learning. *Journal of educational psychology*, *104*(2), 485.
- Ustun, A. B., & Tracey, M. W. (2021). An innovative way of designing blended learning through design-based research in higher education. *Turkish Online Journal of Distance Education*, *22*(2), 126-146.
- Van Dam, N. H. (2017). The 4th industrial revolution & the future of jobs. *Bookboon. Retrieved October*, *13*(2018), 1071-1084.
- Van der Meer, N., van der Werf, V., Brinkman, W. P., & Specht, M. (2023). Virtual reality and collaborative learning: A systematic literature review. *Frontiers in Virtual Reality*, *4*, 1159905.
- Van der Wel, P., & Van Steenbergen, H. (2018). Pupil dilation as an index of effort in cognitive control tasks: A review. *Psychonomic bulletin & review*, *25*(6), 2005-2015.
- van Limpt, H. A. T., Nilsenova, M., & Louwerse, M. M. (2020). Awe yields learning: A virtual reality study. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 42).
- Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS quarterly*, 425-478.
- Venkatesh, V., Thong, J. Y., & Xu, X. (2012). Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. *MIS quarterly*, 157-178.
- Vinchon, F., Lubart, T., Bartolotta, S., Gironnay, V., Botella, M., Bourgeois-Bougrine, S., ... & Gaggioli, A. (2023). Artificial intelligence & creativity: A manifesto for collaboration. *The Journal of Creative Behavior*, *57*(4), 472-484.
- Vogl, E., Pekrun, R., Murayama, K., Loderer, K., & Schubert, S. (2019). Surprise, curiosity, and confusion promote knowledge exploration: Evidence for robust effects of epistemic emotions. *Frontiers in psychology*, *10*, 2474.
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes* (Vol. 86). Harvard university press.
- Wakeman, C. A., Bagtzoglou, A., & Chrysochoou, M. (2022, April). Improving the Learning Experience of Neurodiverse Students in a Fluid Mechanics Course During the COVID-19 Pandemic. In *ASEE-NE 2022*.
- Waller, D., Hunt, E., & Knapp, D. (1998). The transfer of spatial knowledge in virtual environment training. *Presence*, *7*(2), 129-143.
- Waller, D., Loomis, J. M., & Haun, D. B. (2004). Body-based senses enhance knowledge of directions in large-scale environments. *Psychonomic bulletin & review*, *11*(1), 157-163.

- Walters, C., Charles, J., & Bingham, S. (2017). Impact of short-term study abroad experiences on transformative learning: A comparison of programs at 6 weeks. *Journal of Transformative Education*, *15*(2), 103-121.
- Wang, C. C., & Hsu, M. C. (2013). Flow experience and challenge-skill balance in e-learning.
- Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational technology research and development*, *53*(4), 5-23.
- Wang, J., Ma, Q., & Wei, X. (2023). The application of extended reality technology in architectural design education: A review. *Buildings*, *13*(12), 2931.
- Wang, Y. H. (2020). Design-based research on integrating learning technology tools into higher education classes to achieve active learning. *Computers & Education*, *156*, 103935.
- Waterworth, J., & Riva, G. (2014). Presence as the Link between Intention and Action. In *Feeling Present in the Physical World and in Computer-Mediated Environments* (pp. 26-44). London: Palgrave Macmillan UK.
- Wei, Z., Liao, J., Lee, L. H., Qu, H., & Xu, X. (2025). Towards Enhanced Learning through Presence: A Systematic Review of Presence in Virtual Reality Across Tasks and Disciplines. *arXiv preprint arXiv:2504.13845*.
- Weidlich, J., & Bastiaens, T. J. (2017). Explaining social presence and the quality of online learning with the SIPS model. *Computers in Human Behavior*, *72*, 479-487.
- Weller, M. (2020). *25 years of ed tech*. Athabasca University Press.
- Widyastuti, E. (2019, March). Using the ADDIE model to develop learning material for actuarial mathematics. In *Journal of Physics: Conference Series* (Vol. 1188, No. 1, p. 012052). IOP Publishing.
- Williamon, A., Aufegger, L., & Eiholzer, H. (2014). Simulating and stimulating performance: introducing distributed simulation to enhance musical learning and performance. *Frontiers in psychology*, *5*, 25.
- Williamson, B. (2017). Big data in education: The digital future of learning, policy and practice.
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic bulletin & review*, *9*(4), 625-636.
- Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence*, *7*(3), 225-240.
- Won, M., Ungu, D. A. K., Matovu, H., Treagust, D. F., Tsai, C. C., Park, J., ... & Tasker, R. (2023). Diverse approaches to learning with immersive Virtual Reality identified from a systematic review. *Computers & Education*, *195*, 104701.
- Wong, D. (2007). Beyond control and rationality: Dewey, aesthetics, motivation, and educative experiences. *Teachers college record*, *109*(1), 192-220.

- Wood, D., & Bilsborow, C. (2015). I am not a person with a creative mind': Facilitating creativity in the undergraduate curriculum through a design-based research approach. *Leading Issues in elearning*, *2*(79), 203-224.
- Yalom, I. D., & Leszcz, M. (2020). *The theory and practice of group psychotherapy*. Hachette UK.
- Yan, L., Martinez-Maldonado, R., Swiecki, Z., Zhao, L., Li, X., & Gašević, D. (2024). Dissecting the temporal dynamics of embodied collaborative learning using multimodal learning analytics. *Journal of Educational Psychology*.
- Yee, N., & Bailenson, J. (2007). The Proteus effect: The effect of transformed self-representation on behavior. *Human communication research, 33*(3), 271-290.
- Yilmaz, R., Aydemir, M., Karaman, S., & Goktas, Y. (2016). Social presence in a three-dimensional virtual world used for distance education. *Croatian Journal of Education: Hrvatski časopis za odgoj i obrazovanje*, *18*(3), 859-897.
- Young, G. W., Stehle, S., Walsh, B. Y., & Tiri, E. (2020). Exploring virtual reality in the higher education classroom: Using VR to build knowledge and understanding. *Journal of Universal Computer Science*, (8), 904-928.
- Yu, Z., & Xu, W. (2022). A meta-analysis and systematic review of the effect of virtual reality technology on users' learning outcomes. *Computer applications in engineering education*, *30*(5), 1470-1484.
- Zanchetta, M. S., Bailey, A., Kolisnyk, O., Baku, L., Schwind, J., Osino, E., ... & Yu, L. (2017). Mentors' and mentees' intellectual-partnership through the lens of the Transformative Learning Theory. *Nurse education in practice*, *25*, 111-120.
- Zeng, H., & Luo, J. (2024). Effectiveness of synchronous and asynchronous online learning: a meta-analysis. *Interactive Learning Environments*, *32*(8), 4297-4313.
- Zhao, R., & Cleesuntorn, A. (2023). Behavioral intention and use Behavior of University students in Chengdu in using virtual reality technology for learning. *Scholar: Human Sciences*, *15*(1), 91-102.
- Zimmerman, B. J. (2000). Self-efficacy: An essential motive to learn. *Contemporary educational psychology*, *25*(1), 82-91.
- Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory into practice*, *41*(2), 64-70.